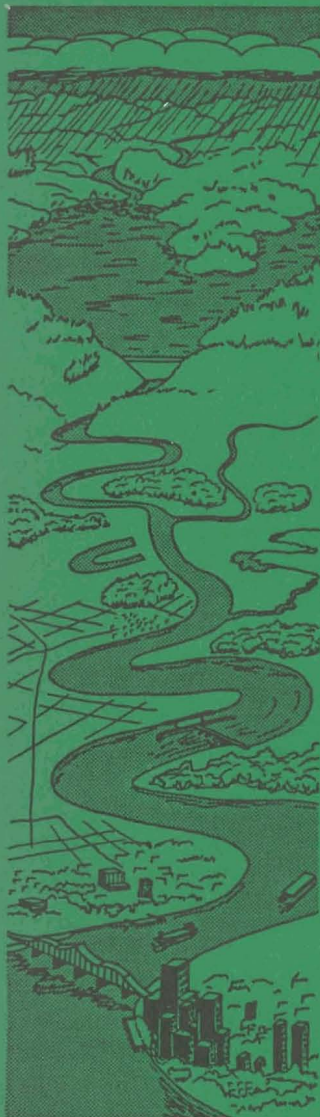




US Army Corps
of Engineers



ENVIRONMENTAL AND WATER QUALITY OPERATIONAL STUDIES

TECHNICAL REPORT E-86-14

SPATIAL AND TEMPORAL DISTRIBUTION OF SULFIDE AND REDUCED METALS IN THE TAILWATER OF NARROWS DAM (LAKE GREESON), ARKANSAS

by

Joe Nix

Department of Chemistry
Ouachita Baptist University
Arkadelphia, Arkansas 71923



November 1986

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Contract No. DACW38-81-0171
(EWQOS Work Unit VIIA)

Monitored by Environmental Laboratory
US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39180-0631



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188 Exp. Date: Jun 30, 1986	
1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S) Technical Report E-86-14		
6a. NAME OF PERFORMING ORGANIZATION Ouachita Baptist University Department of Chemistry		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USAEWES Environmental Laboratory		
6c. ADDRESS (City, State, and ZIP Code) Arkadelphia, Arkansas 71923			7b. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Corps of Engineers		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. DACW38-81-0171		
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO. EWQOS Work Unit VIIA	PROJECT NO.	TASK NO.
					WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Spatial and Temporal Distribution of Sulfide and Reduced Metals in the Tailwater of Narrows Dam (Lake Greeson), Arkansas					
12. PERSONAL AUTHOR(S) Nix, Joe					
13a. TYPE OF REPORT Final report		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day) November 1986	
				15. PAGE COUNT 106	
16. SUPPLEMENTARY NOTATION Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Dissolved oxygen Little Missouri River Sulfide Tailwater		
			Iron Manganese Narrows Dam		
			Lake Greeson Metals Reservoir		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>Water quality problems in tailwater areas are frequently related to water quality conditions in the reservoir. Of particular concern are elevated concentrations of sulfide and reduced metals, such as iron and manganese. Field investigations at Narrows Dam (Lake Greeson), located on the Little Missouri River in southwest Arkansas, document temporal and spatial patterns in the distribution of sulfide and reduced metals within and below a hydropower reservoir. Laboratory experiments involving reaeration of anoxic hypolimnetic waters were conducted to evaluate factors influencing the oxidation of various reduced metals. These results are compared with field observations.</p>					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Preface

The studies presented in this report were sponsored by the Environmental and Water Quality Operational Studies (EWQOS) Program, Work Unit VIIA. The EWQOS Program is sponsored by the Office, Chief of Engineers (OCE), US Army, and is assigned to the US Army Engineer Waterways Experiment Station (WES), under the purview of the Environmental Laboratory (EL). The studies described herein represent a portion of the work performed under Contract No. DACW38-81-0171 for the US Army Engineer District (USAED), Vicksburg. The OCE Technical Monitors for the EWQOS Program were Dr. John Bushman, Mr. Earl Eiker, and Mr. James Gottesman. Dr. Jerome L. Mahloch was the Program Manager of EWQOS.

This report was prepared by Dr. Joe Nix, Department of Chemistry, Ouachita Baptist University, Arkadelphia, Ark. The Contracting Officer's Representative for the contract was Dr. Richard Price, Chief, Water Quality Section, Engineering Division, USAED, Vicksburg. The studies were conducted under the direct supervision of Dr. Robert H. Kennedy, Aquatic Processes and Effects Group (APEG), EL, and Dr. Price, and under the general supervision of Dr. Thomas L. Hart, Chief, APEG; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, EL. This report was edited by Ms. Jessica S. Ruff of the WES Information Products Division.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

This report should be cited as follows:

Nix, J. 1986. "Spatial and Temporal Distribution of Sulfide and Reduced Metals in the Tailwater of Narrows Dam (Lake Greeson), Arkansas," Technical Report E-86-14, prepared by Ouachita Baptist University, Arkadelphia, Ark., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Contents

	<u>Page</u>
Preface	1
Introduction	3
Background	3
Study area description	5
Methods and Materials	8
Results and Discussion	18
References	33
Appendix A: Field Determination of Hydrogen Sulfide in Water . .	A1
Materials	A2
Procedure	A3
Appendix B: Data Listings, Lake Greeson and Little Missouri River, May-December 1983	B1

SPATIAL AND TEMPORAL DISTRIBUTION OF SULFIDE AND REDUCED METALS IN THE
TAILWATER OF NARROWS DAM (LAKE GREESON), ARKANSAS

Introduction

Background

1. As early as 1957, Ingols pointed out the potential water quality impacts of hydroelectric power generation. Since that time, numerous studies have documented that reduced materials are often released from the hypolimnion of seasonally anoxic reservoirs during the late period of stratification. Many studies have been conducted to determine the effect that releases from coldwater impoundments have on the receiving stream (Walburg et al. 1981). A large percentage of these studies have dealt with the impact on various biological systems and, in general, have focused on the effect of decreased temperature.

2. A recent review by Gordon (1983) has summarized the literature dealing with some of the chemical aspects of water released from the hypolimnion of low-level release impoundments. In particular, this review dealt with the occurrence of iron, manganese, and sulfide in the stream and lake environment. These three chemical species are the most common constituents to appear in the hypolimnion of lakes and reservoirs in reduced states.

3. As pointed out by Gordon (1983), very little systematic work has been conducted to evaluate the distribution and dynamics of reduced materials after they are released into the tailwater environment. Subsequently, Gordon (1984) conducted such an investigation of the Duck River below Normandy Dam.

4. The removal of Fe^{+2} , Mn^{+2} , and hydrogen sulfide (H_2S) appears to occur primarily by oxidation. The oxidation process is initiated at the time of oxygenation of the hypolimnetic water. Aeration of the release water may take place in the tailrace or, in some cases, within the turbine. The reduced iron species (Fe^{+2}) released from the hypolimnion is usually oxidized quickly to the +3 state, resulting in

the formation of an insoluble hydrous oxide of iron. This hydrous oxide can settle from the water column or remain suspended, often as particles of colloidal size. The removal of manganese from the tailwater of dams appears to be somewhat slower than iron and may involve more than direct oxidation to the insoluble +4 state. Theoretical treatments of the rate of manganese oxidation (Wilson 1980), along with laboratory studies designed to determine the rate of oxidation of manganese, indicate that at the pH of most stream systems, the rate would be very slow and thus cannot be used to explain the observed removal of manganese in actual tailwater situations. It has been suggested that this removal may involve absorption and possibly autocatalytic oxidation (Stumm and Morgan 1970).

5. Sulfide is generally considered very unstable after its introduction into an oxygenated environment. In addition to degassing, H_2S can be removed by oxidation, leading to the production of sulfate (Garrels and Christ 1965). The study of H_2S in the tailwater of dams and at stations downstream from the dam is complicated by the limitations of the analytical chemistry of H_2S . Hydrogen sulfide is generally considered a "fleeting species" and is somewhat chemically illusive. Its determination requires a quick field determination or extensive preservation techniques which may not be appropriate at very low concentrations. The idometric titration method recommended for the determination of sulfide (US Environmental Protection Agency (USEPA) 1976; American Public Health Association (APHA 1980) Standard Methods) does not have the sensitivity needed to show the detailed distribution of this species in most tailwater environments. Detection limits on the order of 0.01 mg/l are needed in order to obtain the spatial distribution of this species at stations located downstream from most dams.

6. Other than the recent work by Gordon (1984) and an earlier study by Gordon and Bonner (1983), little attention has been focused on the dynamics of the removal of reduced chemical species from the tailwaters of coldwater-release dams. Several studies have attempted to sample tailwaters, but little attention has been given to aspects such as time of travel of the water after its release. Sampling of the

tailwaters of streams at varying distances downstream from a dam will not give a meaningful picture of removal rates unless appropriate "lag times," as determined by time-of-travel studies, are applied. Ideally, one would want to sample a parcel of water as it left a dam, then sample the same parcel at varying distances (times) below the dam.

7. In order to predict arrival times at various downstream stations, a clear understanding of the dynamics of the tailwater must be obtained. Once the factors that influence arrival time have been addressed, it should be possible to sample the stream at various downstream stations with some degree of certainty as to the time when the water being sampled left the dam. Using this approach, it should be possible to determine actual removal rates of reduced chemical species introduced into the tailwater.

Study area description

8. Narrows Dam on the Little Missouri River in southwest Arkansas was constructed by the Corps of Engineers in 1950. Characteristics of Lake Greeson, which was formed by this dam, are summarized below.

<u>Characteristic</u>	<u>Value</u>
Drainage area	614 km ²
Maximum power pool elevation	167.1 m NGVD
Maximum power pool area	29.4 km ²
Storage of conservation pool plus power pool	3.45×10^8 m ³
Center-line elevation of penstock	148.8 m NGVD

9. Lake Greeson has been observed to stratify and develop a seasonally anoxic hypolimnion (Nix 1979). The depth of the penstock is such that anaerobic releases are observed during the late summer and fall seasons most years. The actual period of anaerobic releases as well as the concentration of reduced chemical species resulting from the anaerobic conditions vary from year to year.

10. Anaerobic conditions first develop in the reservoir at the sediment/water interface and gradually progress up the water column during the stratified period. Elevated concentrations of reduced metals, such as Mn^{+2} , Fe^{+2} , and H_2S closely follow the development of the anaerobic conditions. In some reservoirs, the extent of the anaerobic zone may progress upward until sulfide and reduced metals are found at the elevation of the penstock. This, however, does not occur in Lake Greeson. Although anaerobic conditions develop at the sediment/water interface and begin to extend into the hypolimnion, these conditions do not extend directly to the elevation of the penstock. Rather, a dissolved oxygen (DO) minimum begins to develop near the elevation of the penstock during early summer and finally becomes anaerobic toward midsummer. Subsequently, reduced chemical species appear in this layer and can be released into the tailwater during periods of generation. Nix (1981) has suggested that the origin of the reduced metals in the metalimnetic region is due to the entrainment of upstream hypolimnetic water in a density current within the thermocline region of the reservoir. This process results in moderately high concentrations of reduced chemical species at the elevation of the penstock while much lower concentrations are observed above and below this elevation.

11. Narrows Dam is used for the production of peaking power. During the summer and early fall, generation may occur for short periods of time or may extend over several hours. By late fall, the frequency of generation usually decreased in response to lower rainfall. The Little Missouri River below Narrows Dam is easily accessible at several downstream locations. Since the tailwater of Narrows Dam has been observed to become anoxic during the summer and fall and since it is easily accessible, this tailwater was chosen as a site to investigate the rates of removal of sulfide and selected reduced metals. Sampling stations were established from the dam to several points below the dam. Studies were conducted to estimate the time of flow to each of the established stations during standard release conditions. Subsequently, samples were secured from each station during the period when reduced chemical species were being released into the tailwater.

12. In an effort to simulate the chemistry of tailwater conditions, water was taken from Lake Greeson at a depth corresponding to the depth of the penstock and then oxygenated in the laboratory. Artificial hypolimnetic water was also made by placing sediment from Lake Greeson in contact with lake water in a sealed container. The artificial hypolimnetic water was also used in experiments designed to investigate the rate of removal of reduced metals following oxygenation.

13. Laboratory oxidation experiments showed no appreciable removal of manganese over a 48-hr period. This confirms previous observations that oxidation of manganese in laboratory conditions occurs at a very slow rate (Delfino and Lee 1968). Since autocatalysis oxidation has been suggested as a removal mechanism (Stumm and Morgan 1970), solid manganese dioxide was added to the oxidation experiments. With manganese dioxide present, reduced manganese was observed to be removed at a much faster rate. Gravels from the tailwater of Narrows Dam, which were coated with hydrous oxides of manganese (black), were substituted for the manganese oxide and found to cause a similar increase in removal rate.

14. The observation that the hydrous oxide-coated gravels significantly impact the rate of removal of manganese from solution prompted an investigation of the fate of other metal ions under similar conditions. The absorption of cobalt and copper onto the hydrous oxides of manganese had been reported (Gray and Malati 1979, Hasany and Qureshi 1981). Laboratory experiments confirmed that the hydrous oxide-coated gravels present in the tailwater of Narrows Dam serve as a sink for cobalt, copper, nickel, lead, silver, cadmium, and zinc. These results suggest that the presence of abundant hydrous oxide-coated gravels present in the tailwaters of coldwater-release dams may be a significant factor in regulating the chemistry of these environments.

Methods and Materials

15. Eight stations were established downstream from Narrows Dam, at the locations shown in Figure 1. Station A was located immediately below Narrows Dam, while Station H was 36.3 km below the dam.

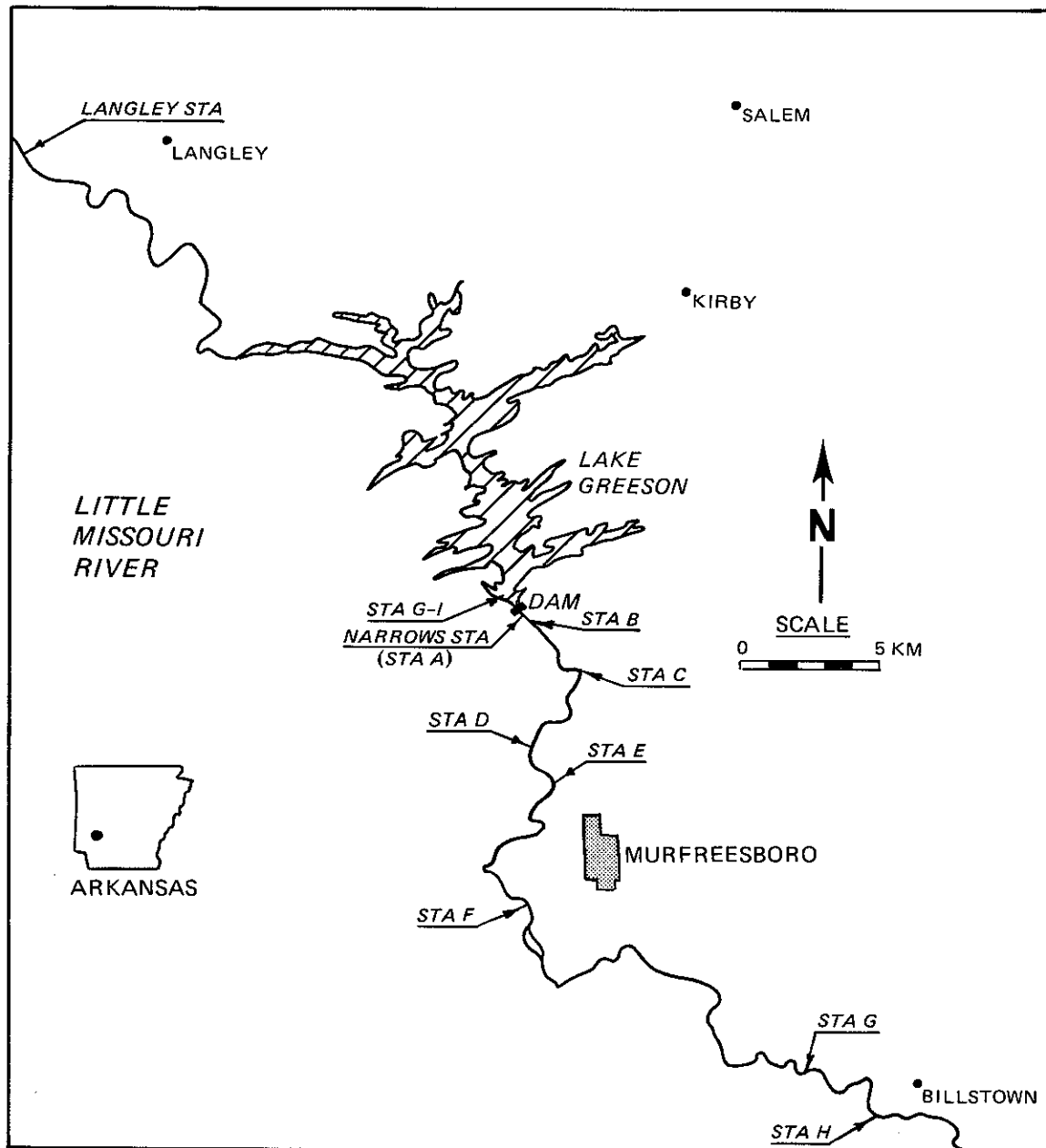


Figure 1. Map of Little Missouri River and Lake Greeson showing location of the eight sampling stations

16. Martek Water Quality Analyzer systems were operative at Stations A, E, and G during most of this study. These instruments measure and record temperature, DO, pH, and specific conductance at 30-min intervals (Nix 1985).

17. The first phase of the study involved an investigation of the tailwater of Narrows Dam in order to determine factors which might influence time of travel. A careful analysis of the data recorded by the Martek unit at Station A indicated that during periods when no generation is taking place, the leakage from the reservoir constitutes the flow in the tailwater. As shown in Figure 2, the leak water is colder than release water. Diurnal warming of this relatively small amount of

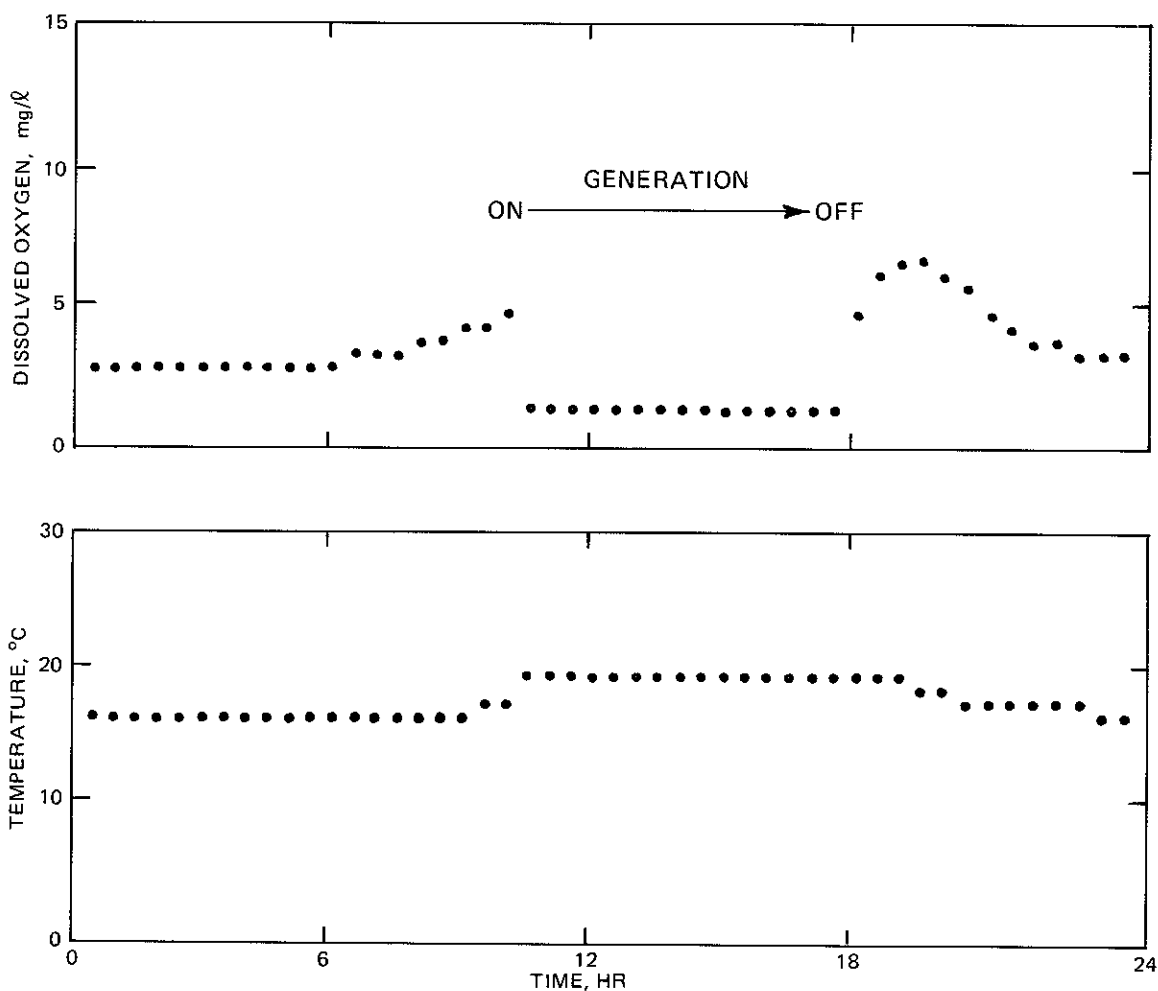


Figure 2. Temperature and DO recorded at Station A, immediately downstream from Narrows Dam, 4 August 1983

water was also observed, as shown in Figure 3. Figure 2 shows data from Station A on a day when generation occurred. The slight increase in

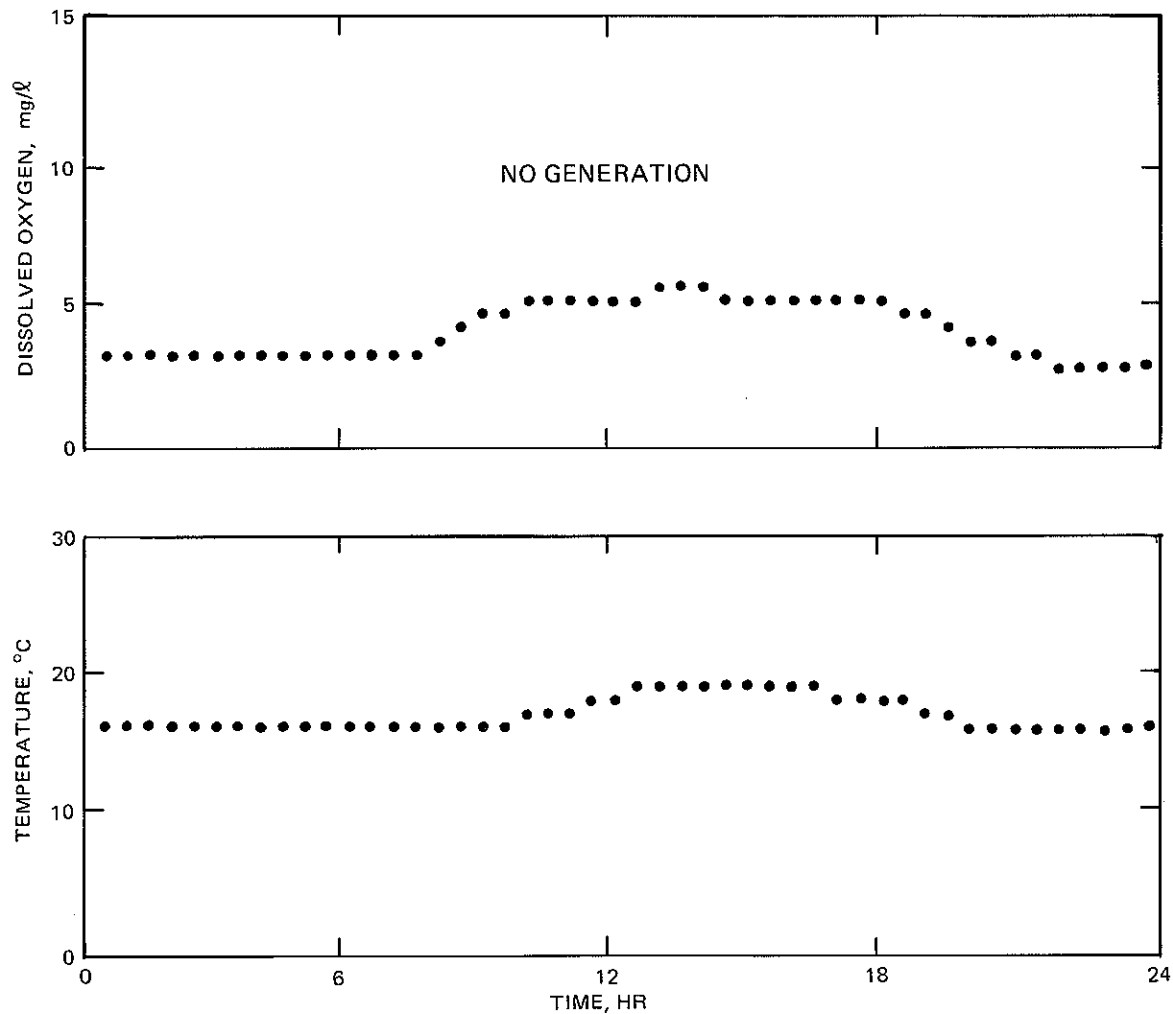


Figure 3. Temperature and DO recorded at Station A, immediately downstream from Narrows Dam, 3 August 1983

temperature observed as generation began indicates that the leak water which was present prior to generation was colder than the release water. Lowered DO concentrations also mark the period of generation, but this quickly recovered as the cold leak water replaced the water released through the penstock.

18. During the period of this study, full generation consisted of releases through three generators. Assuming normal reservoir elevation, this condition results in a discharge of 70 cu m/sec. Reservoir

elevation varied only slightly during the period of the study. Although there may have been some slight variations in discharge, it is likely that these were small compared to the overall discharge. For the purpose of this study it is assumed that during "full release conditions," the discharge is essentially constant.

19. The initial attempt to estimate time of flow to downstream stations was carried out by observing stream temperature and river elevation prior to the arrival of the power wake, with observations continuing through stabilization as the power wave arrived. The results of the observations made at Stations B, C, and D are shown in Figure 4. By assuming that stabilization at a minimum temperature indicates the arrival of freshly released reservoir water, it is clear that stream elevation begins to increase prior to the arrival of the freshly released water. The water in the initial rise consists of water that had warmed significantly since the previous release period. Thus, the stabilization of a minimum temperature at each station should be a better indicator of the presence of freshly released reservoir water as compared to river elevation.

20. During the week of 20 June 1983, Ryan temperature monitors were implanted at each of the eight downstream stations indicated in Figure 1. The results of the data retrieved from these monitors for a 2.5-day period are shown in Figure 5. The time of travel to each of the stations was estimated by measuring the length of time from the beginning of generation until a minimum temperature was reached at each station. This resulted in a time of travel of approximately 22 hr to the most downstream station. The estimated time of travel, river distance, and elevation of each station are given in Table 1.

21. Before studies designed to determine removal rates of reduced metals could be conducted, it was necessary to establish that a steady-state condition developed following the onset of generation. To do this, samples were taken at Station B over a period of 7 hr. Results of the analysis of these samples are shown in Figure 6. These data confirm that steady-state conditions develop during a release cycle. Since steady-state conditions appear to be established, the exact time

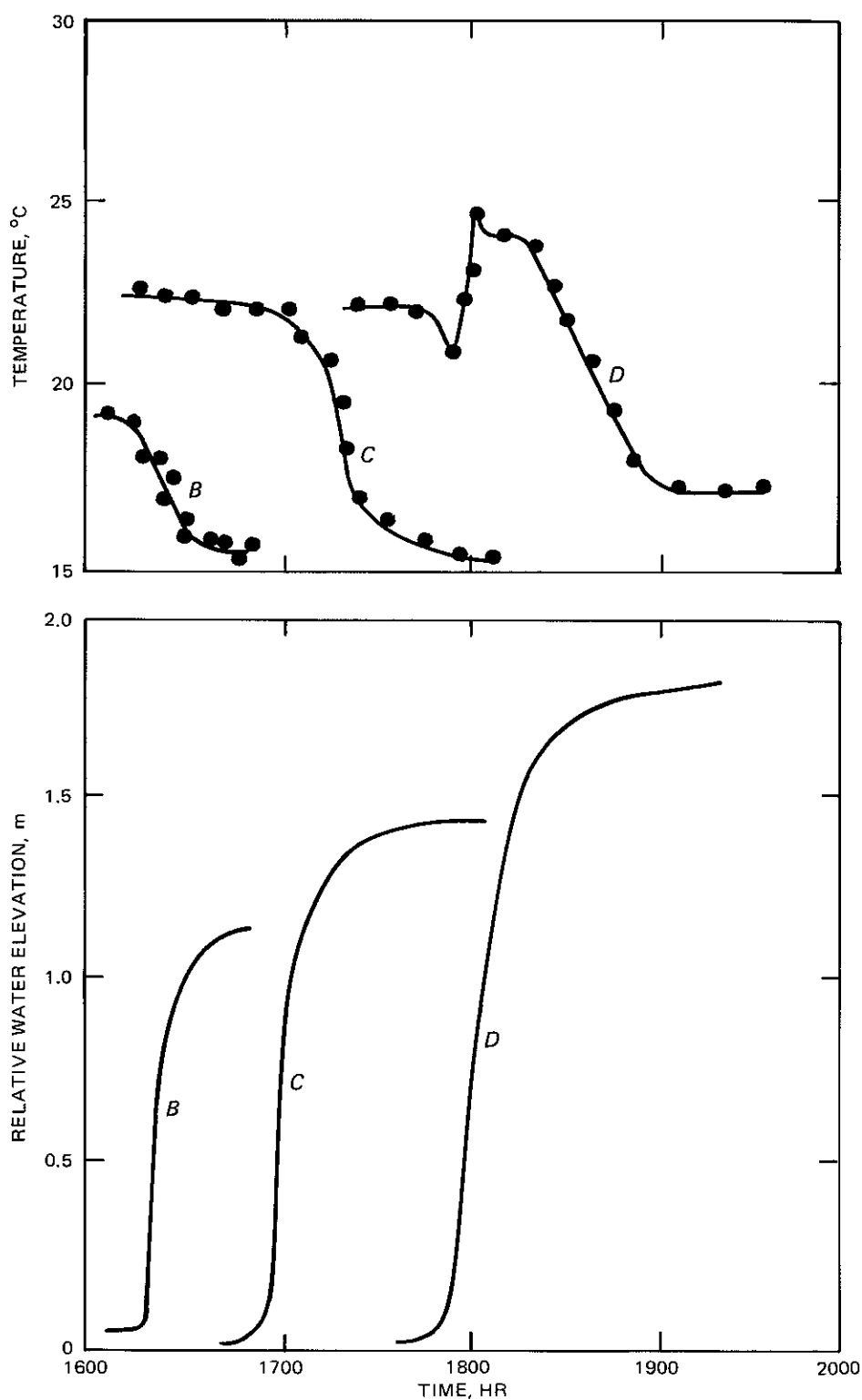


Figure 4. Observation of river elevation and temperature at three stations below Narrows Dam during a generation cycle (generation began at 1600 hr)

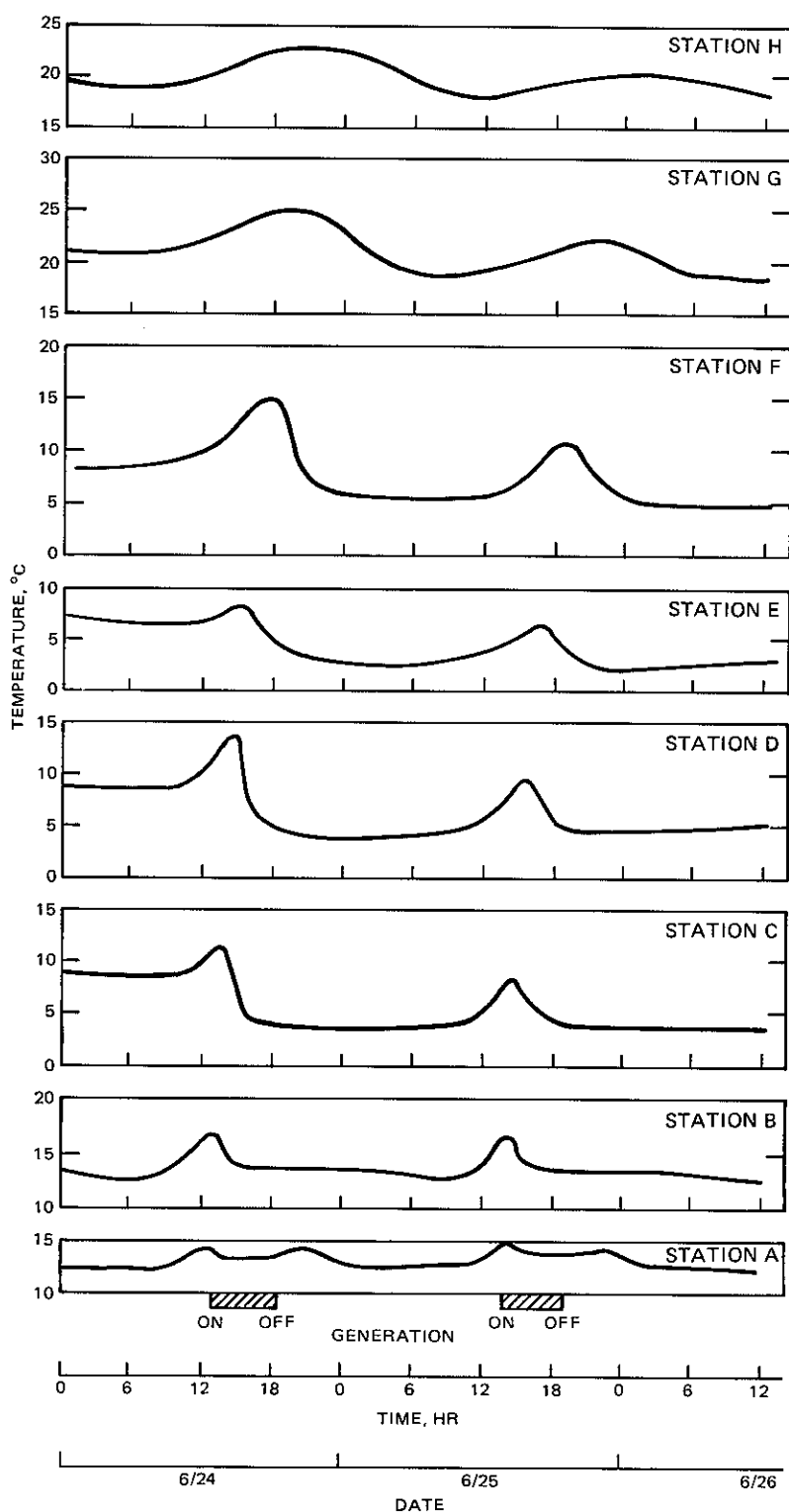


Figure 5. Temperature data at downstream stations on Little Missouri River from 24-26 June 1983, obtained using Ryan temperature monitors

Table 1
River Distance, Elevation, and Estimated Time
of Travel for Each Sampling Station

<u>Station</u>	<u>Distance Below</u> <u>Narrows Dam, km</u>	<u>Elevation</u> <u>m, NGVD</u>	<u>Estimated Time</u> <u>of Travel,* hr</u>
A	0.2	122.0	0.1
B	0.6	120.8	0.5
C	3.7	115.9	2.5
D	8.2	108.3	5.0
E	10.4	106.4	6.5
F	18.2	100.6	9.5
G	27.4	95.2	16.0
H	36.3	85.4	22.0

* Estimated from temperature data from Ryan monitors.

of sampling at downstream locations becomes less critical as long as the sampling time is after the arrival of the freshly released reservoir water but before the river begins to fall. If a sample can be taken within this time frame, it is reasonable to assume that it represents reservoir water released during the designated release cycle.

22. The development of the anaerobic zone in Lake Greeson was monitored by periodically sampling the reservoir at Station G-1 (see Figure 1). Station G-1 is located immediately upstream from Narrows Dam directly over the old river channel. Samples were secured using a van Dorn type sampler, while temperature, DO, pH, and specific conductance were measured in situ using a Martek Mark V water quality analysis system. The field instrument was calibrated prior to each day's use.

23. Martek Mark VIII recording water quality monitoring systems were located at Narrows Dam, Station E, and Station G. The instruments were housed in metal boxes. The sensor package was located in a well-mixed portion of the stream. These instruments were calibrated weekly by adjusting the calibration controls to cause the readings of the Mark VIII to coincide with an instrument that had been calibrated in the

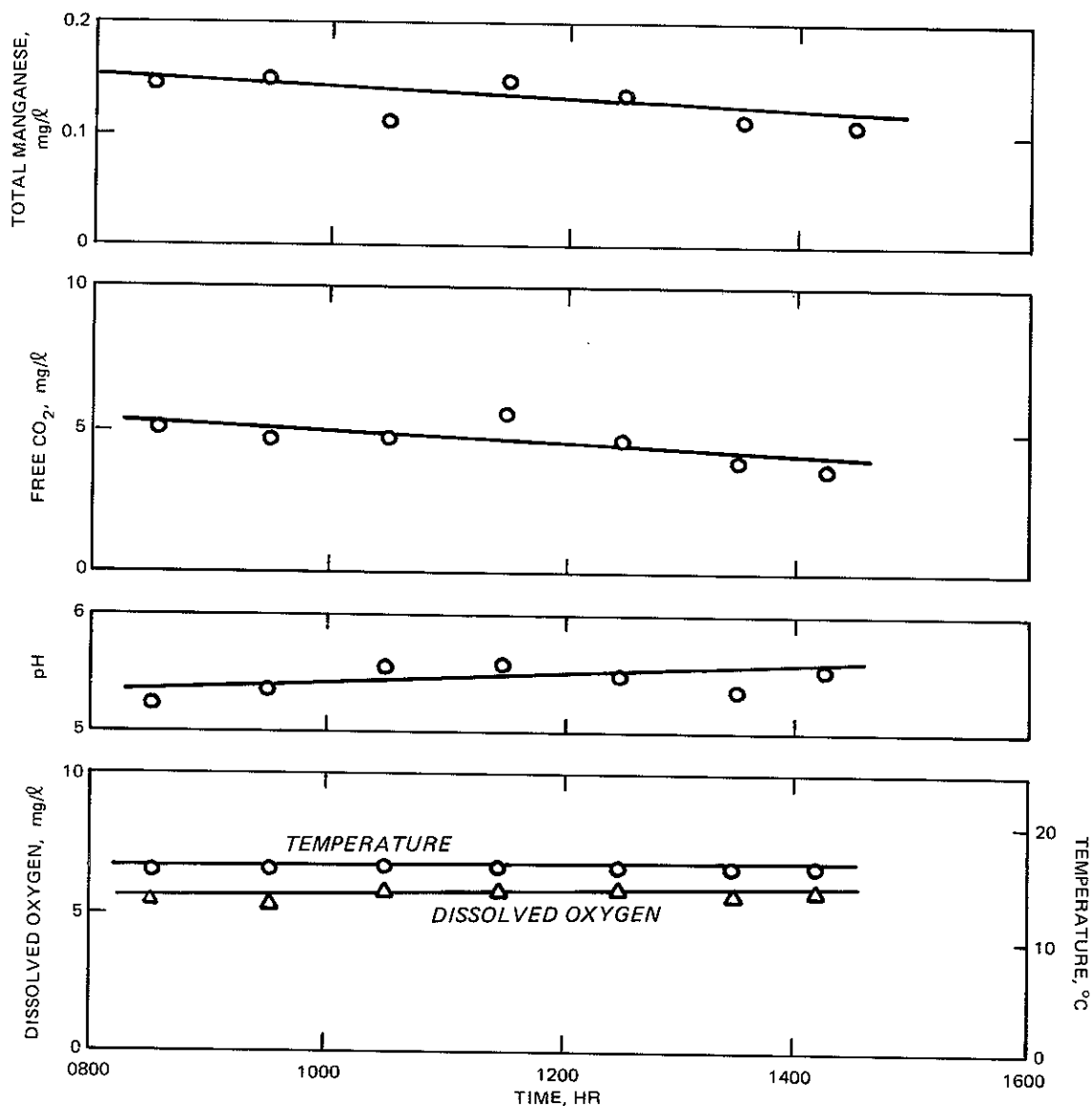


Figure 6. Selected water quality parameters from samples taken at Station B, 12 June 1983 (generation began at 0730 hr)

laboratory earlier the same day. These instruments were programmed to record temperature, DO, pH, and specific conductance at 30-min intervals. Data were recorded and stored on cassette tapes which were subsequently read into the memory of a Vax 750 computer.

24. Water samples from the reservoir and from river stations were processed according to the scheme shown in Table 2. All methods used

Table 2
Scheme for Handling, Processing, and Analyzing Water Samples

<u>Fraction</u>	<u>Handling and Processing</u>	<u>Analyses</u>
A	Raw sample stored at 4° C	Chloride Sulfate Turbidity Sulfide* Alkalinity* pH* Free CO ₂
B	Raw sample acidified with H ₂ SO ₄ and stored at 4° C	Total phosphorus Total Kjeldahl nitrogen
C	Raw sample acidified with HNO ₃	Total sodium Total potassium Total calcium Total magnesium Total iron Total manganese
D	Filtered (0.45 μ) and stored at 4° C	Nitrate nitrogen Soluble reactive phosphorus Silica
E	Filtered (0.1 μ) and acidified with HNO ₃	Dissolved iron Dissolved manganese
F	Filtered (glass fiber), acidi- fied with H ₂ SO ₄ , and stored in glass at 4° C	Total organic carbon

* Field determination.

were those recommended in Standard Methods (APHA 1980) or by the USEPA (1976) with the exception of that for H₂S. The analysis of samples for H₂S was accomplished using a modified electrode method that is described in Appendix A. A summary of analytical methods used is given in Table 3. It should be noted that sulfide, alkalinity, and free carbon dioxide (CO₂) were analyzed in the field within a few minutes of sampling.

Table 3
Analytical Methods

<u>Water Quality Parameter</u>	<u>Method and Reference</u>
pH	Electrode method
Alkalinity	Titration, Standard Method
Sodium	AAS (flame); EPA Method 273.1
Potassium	AAS (flame); EPA Method 258.1
Calcium	AAS (flame); EPA Method 215.1
Magnesium	AAS (flame); EPA Method 242.1
Chloride	Ion chromatography; National Surface Water Survey, EPA, 1984 Draft
Sulfate	Ion chromatography; National Surface Water Survey, EPA, 1984 Draft
Nitrate nitrogen	Ion chromatography; National Surface Water Survey, EPA, 1984 Draft
Ammonia nitrogen	Specific ion electrode
Total Kjeldahl nitrogen (TKN)	EPA Method 341.1 (modified for manual determination)
Total dissolved phosphorus (TDP)	EPA Method 365.4 (modified for manual determination)
Silica	EPA Method 370.1 (modified for manual determination)
Total organic carbon (TOC)	Persulfate oxidation; Oceanography International Analyzer
Trace metal	AAS - graphite furnace

Results and Discussion

25. The results of the analysis of samples taken from Lake Greeson and the Little Missouri River downstream from Narrows Dam are given in Appendix B. The following discussion focuses on the development of reduced metals in the reservoir and their disappearance in the tailwater.

26. Using data from the Martek recording instrument located immediately downstream from Narrows Dam, the DO concentration of the Little Missouri River during actual generation periods was noted (Figure 7).

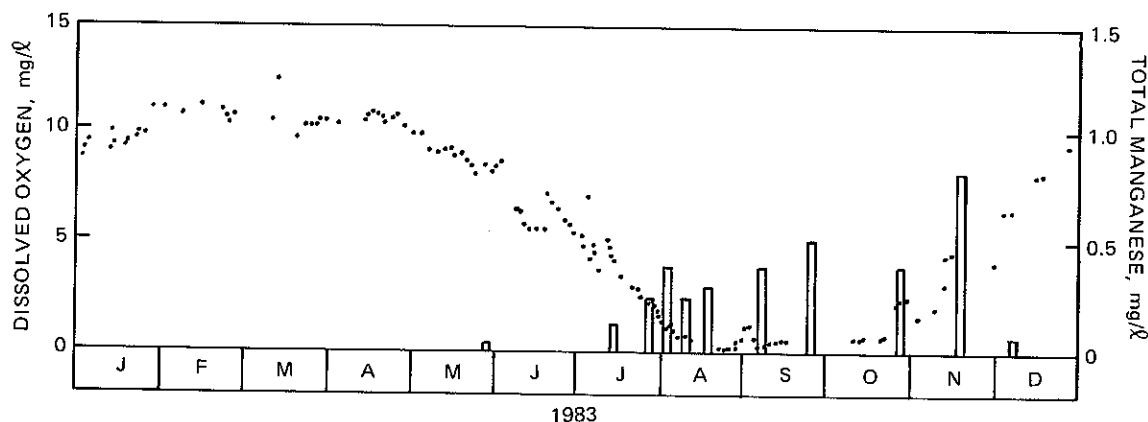


Figure 7. Concentrations of dissolved oxygen (dots) and total manganese (bars) observed at Station A during 1983

Suppression of DO in the tailwater during release periods was observed to begin in early May. By mid-July, the DO in the tailwater had declined to approximately 3 mg/l. At that time the manganese concentration in the tailwater was noted to increase. The DO concentration continued to decrease and became essentially anoxic in mid-August. Manganese and other reduced metals were observed in the tailwater throughout the period from mid-July until mid-November, when DO began to reappear in the reservoir releases.

27. Figures 8, 9, and 10 summarize the DO, manganese, and iron profiles observed in Lake Greeson during the summer and fall of 1983. The depth of the intake structure at Narrows Dam varied from 17 to 18 m during the period of this investigation. As expected, the DO

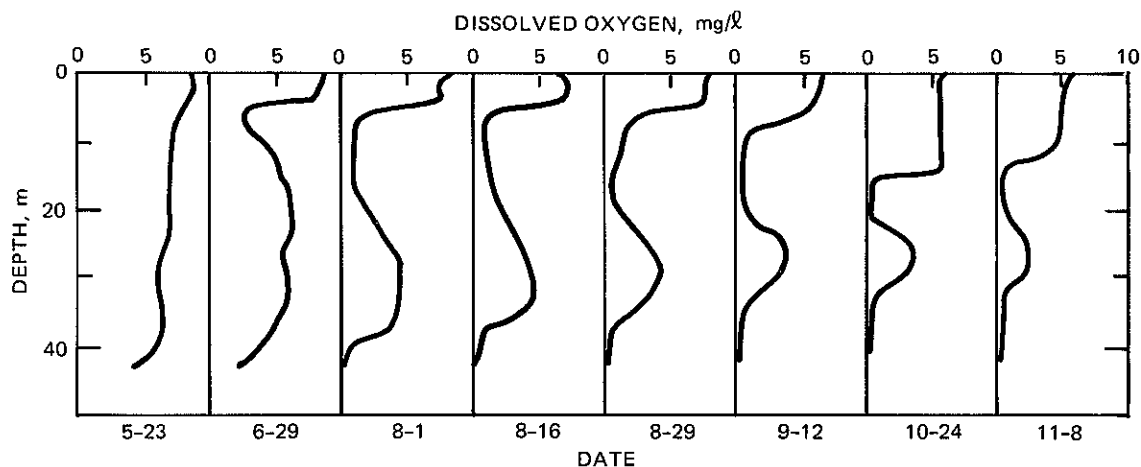


Figure 8. Dissolved oxygen profiles at Station G-1 (Lake Greeson), May–November 1983

concentration of the water at the mud/water interface began to decline in May 1983. The concentration of manganese and iron subsequently increased as the thickness of the anoxic zone moved upward. By late June, a DO minimum was observed in the metalimnetic region, roughly coinciding with the depth of the penstock in Narrows Dam. This metalimnetic zone became essentially anoxic by early August. The concentration of manganese was observed to increase in this zone by mid-August. Increases in the iron concentration in this same region did not occur until mid-September. By early November, the concentration of manganese in this metalimnetic zone was 3.0 mg/l. The distribution of manganese, iron, and DO observed in the late fall suggests that a density current results during generation periods and entrains reduced species from the upstream hypolimnion, as shown in Figure 11 (Nix 1981). This advective transport of water at or near the elevation of the penstock results in the discharge of water with elevated concentrations of reduced metals. As shown by the data presented in Appendix B, concentrations of manganese, iron, and hydrogen sulfide were all elevated in the metalimnetic region. During this period, lower concentrations of reduced metals were observed both above and below the "withdrawal" zone.

28. As shown in Figure 7, the maximum concentration of manganese observed in the tailwater during release periods was approximately 1 mg/l. The fact that even higher concentrations of manganese were

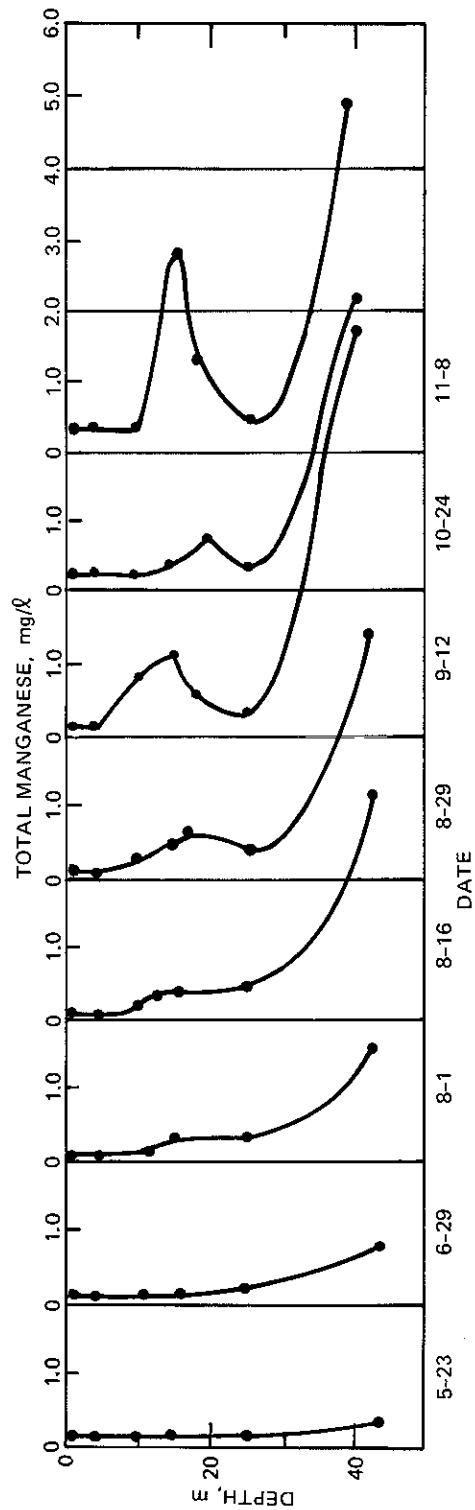
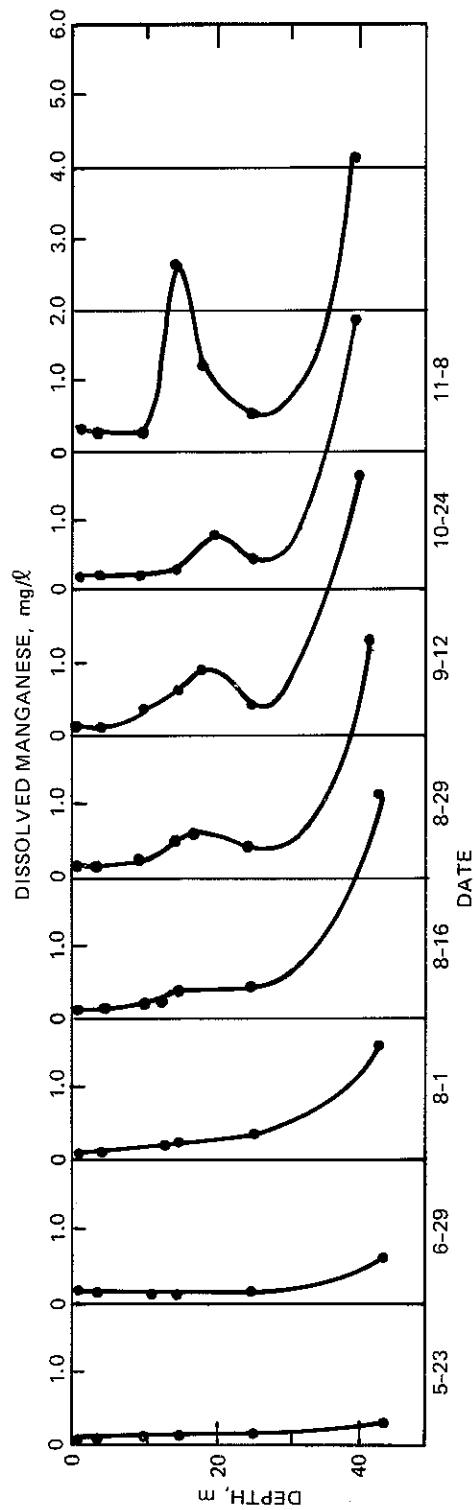


Figure 9. Dissolved manganese and total manganese at Station G-1 (Lake Greeson)
May-November 1983

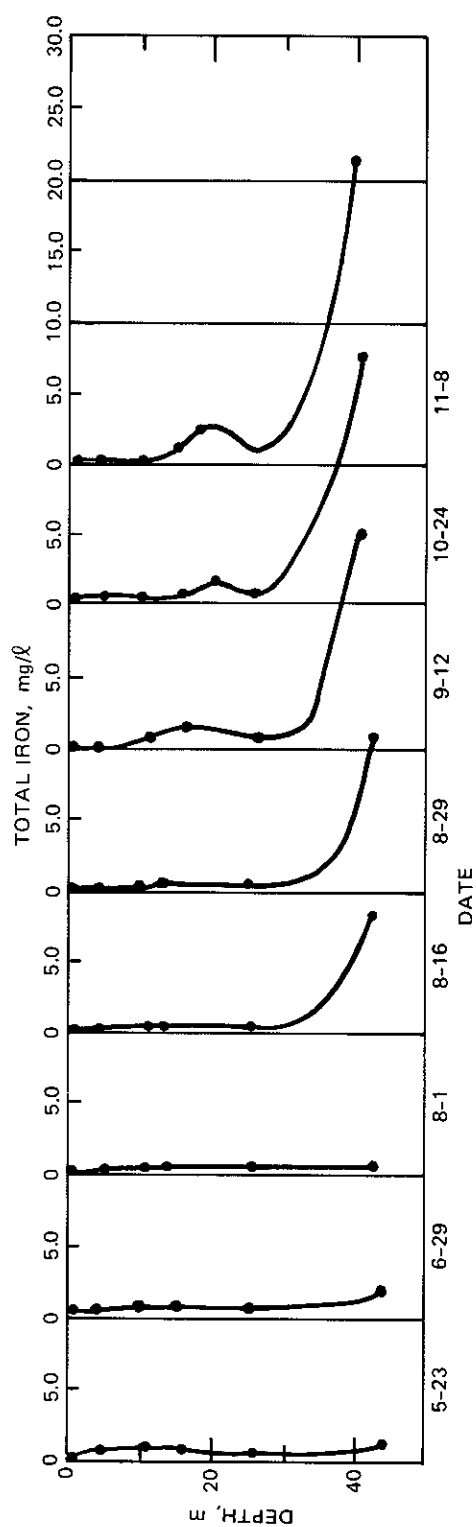
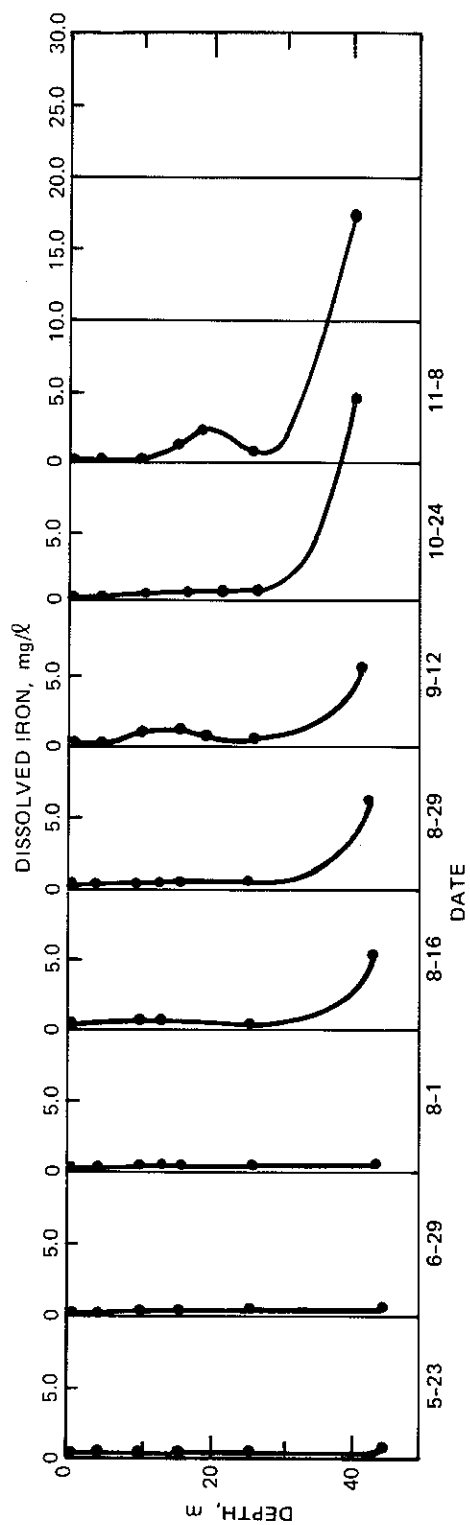


Figure 10. Dissolved iron and total iron at Station G-1 (Lake Greenson),
May-November 1983

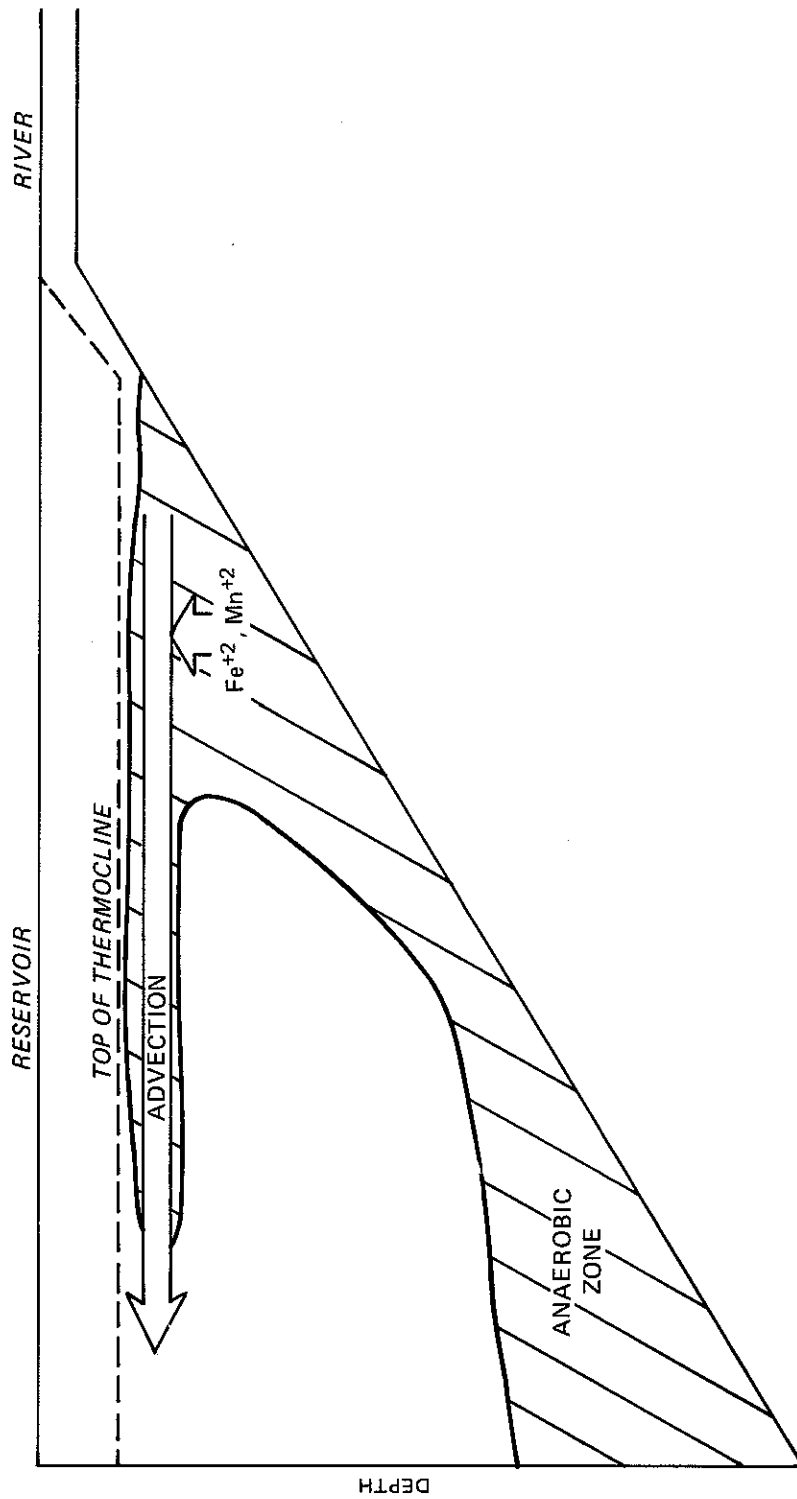


Figure 11. Mechanism for advective transport of reduced species into the metalimnion of the reservoir

observed in the reservoir at the elevation of the penstock suggests that the elevated concentration of manganese is restricted to a relatively thin layer and that the "withdrawal zone" incorporates a considerable amount of water with a lower manganese concentration. This is further supported by the observation that elevated concentrations of manganese were observed to persist even as the DO concentration of the release water began to increase in late November.

29. Figure 12 summarizes the results of the analysis of samples taken at eight stations located downstream from Narrows Dam during a generation cycle which occurred on 6-7 September 1983. The samples were taken at a time which ensured that water from that release cycle was present at each station.

30. Recovery of the DO concentration of the Little Missouri River apparently occurs within the first 18 km of the tailwater (Station F), which corresponds to water that was released from Narrows Dam 9.5 hr earlier. Only a slight warming trend was observed from the dam to the most downstream station, corresponding to a warming rate of only 0.1°C/km or 0.2°C/hr . It should be pointed out that this warming rate was observed during an actual release cycle. During periods when the river is not under the influence of a release cycle, warming probably occurs considerably faster.

31. The loss of free CO_2 and the resulting increase in pH were observed following the release of water from Narrows Dam. Hydrogen sulfide was quickly lost from the stream and reached undetectable levels at a downstream distance of 10 km, corresponding to water which was released 6.5 hr earlier. Both manganese and iron decreased in a downstream direction, with manganese reaching ambient concentration at the most downstream station. Iron removal rates were observed to be slower than those of manganese. The observation that a high percentage of the iron was present in the particulate form (difference in total and dissolved) indicates that iron is being precipitated, then continues to be transported in the particulate form. The fact that the concentration of particulate manganese is very low and that total manganese drops to a very low concentration in the river suggests that the manganese is being

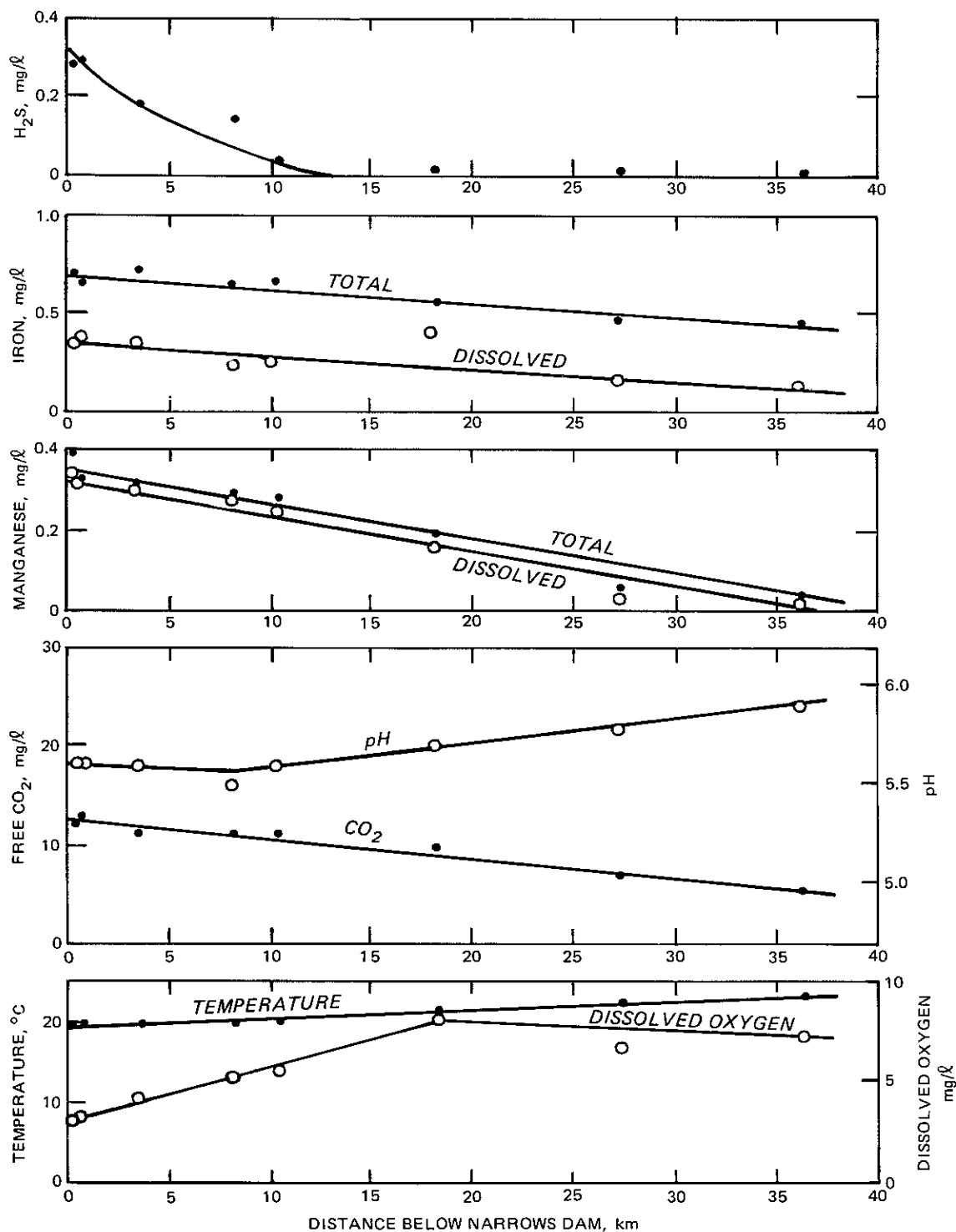


Figure 12. Selected water quality parameters at the eight stations located downstream from Narrows Dam, 6 September 1983. Samples were taken at a time after the beginning of generation which corresponds to the estimated time of travel

deposited in the streambed. This deposition is apparent from the appearance of hydrous oxide-coated gravels throughout the region of the river that was studied. In the section of the tailwater located nearest the dam, the entire riverbed is black from such deposits.

32. Gravels were collected from the bed of the Little Missouri River on 25 June 1983. These gravels, which were black from a coating of a hydrous oxide of manganese, were leached with concentrated hydrochloric acid. The black deposits were completely removed within 2 to 3 min. The resulting solution was diluted and subjected to analysis for manganese, iron, and several other trace metals. The results of this analysis are presented in Table 4. It is obvious that relative to the ratio of manganese to iron present in the tailwater, the gravels are significantly enriched in manganese. This suggests different removal mechanisms for iron and manganese.

33. An attempt was made to collect this hydrous oxide of manganese coating onto a porcelain substrate implanted in the river. Porcelain dishes were placed upside down in the riverbed at each of the downstream stations. After 1 week they were collected. The dishes that were collected from Stations A, B, C, and D were observed to be orange. The other dishes had no apparent coating. The orange coating was stripped from the dishes with hydrochloric acid and analyzed for iron and manganese. The results showed the material to be a compound of iron (probably a hydrous oxide) with very low concentrations of manganese. Subsequent experiments were equally unsuccessful in obtaining a coating that was rich in manganese. The fact that manganese is obviously being deposited on gravels in the river suggests that the nature of the substrate is critical in this process.

34. The rate of removal of manganese from the Little Missouri River during the release cycles observed from August through October ranged from 0.016 to 0.022 mg/l/hr which compares to 0.041 mg/l/hr observed by Gordon (1984) in the Duck River below Normandy Dam. During the rather short period when removal of H_2S was observed in the tailwater of Narrows Dam, the rate was 0.05 mg/l/hr.

Table 4

Analysis of Coating of Five Gravels (Approx. 2 cm) Collected from Tailwater of Narrows Dam

25 June 1983

Sample No.	Manganese	Iron	Lead	Concentration, mg/l*					
				Nickel	Zinc	Copper	Cobalt	Cadmium	Silver
1	124	27	0.005	0.094	0.425	0.052	0.100	0.002	0.000
2	272	44	0.023	0.340	0.642	0.108	0.175	0.007	0.000
3	272	50	0.006	0.375	0.375	0.086	0.200	0.002	0.000
4	208	48	0.004	0.015	0.292	0.258	0.150	0.004	0.000
5	146	24	0.001	0.106	0.262	0.038	0.075	0.002	0.000

* Values reflect metal concentrations in hydrochloric acid leachate.

35. As pointed out by Gordon (1983), numerous investigators have attempted to simulate tailwater conditions by aerating water taken from the hypolimnion of a reservoir under laboratory conditions. In general, these experiments have failed to produce removal rates of manganese as high as those observed in the Duck River below Normandy Dam (Gordon 1984). On three occasions, a 20-l water sample was collected from the deep hypolimnion (36 m) and the metalimnetic region (20 m) of Lake Greenson. The introduction of air into these samples was minimized by pumping the sample into a bottle that had been flushed with nitrogen. These samples were transported to the laboratory, where a portion was transferred to a 4-l beaker equipped with a magnetic stirrer. Samples were removed from this container periodically. The DO concentration in the container was also monitored. The length of observation ranged from 5 to 48 hr. The results of such an experiment, using water taken from a depth of 20 m on 16 November 1983, are shown in Figure 13. A manganese removal rate of 0.006 mg/l/hr was observed. Removal rates in other experiments were found to be similar. No significant differences were noted between removal rates with water taken from the deep hypolimnion and water taken from the metalimnion.

36. Approximately 20 kg of sediment from the bottom of Lake Greenson at Station G-1 was secured using a ponar sampler. The mud was immediately placed in a 200-l polyethylene tank, then covered with Lake Greenson water. The container top was sealed with a silicone sealant. The headspace of the tank was flushed with nitrogen gas, and a slightly positive pressure of nitrogen was maintained to prevent the introduction of oxygen. A glass tube that was sealed into the container permitted removal of water from near the center. Within 1 month, water from the tank showed the presence of reduced manganese and iron. "Artificial hypolimnetic water" from this tank was used in laboratory experiments to determine the removal rates of reduced species. The results of these experiments were very similar to those using water taken from the anoxic zones of Lake Greenson.

37. The autocatalytic oxidation of manganese involving absorption onto the surface of a hydrous oxide of manganese has been suggested as a

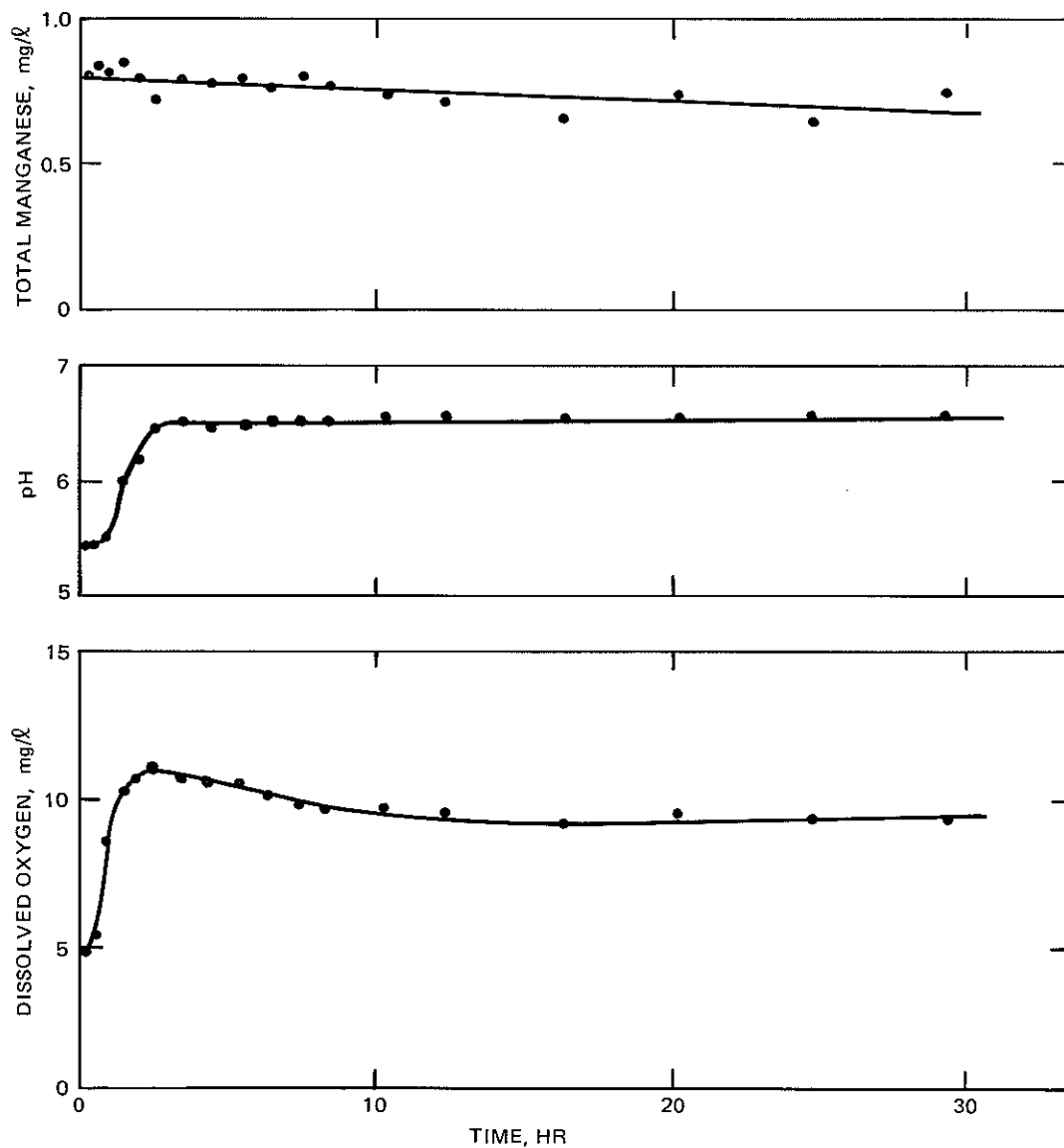


Figure 13. Dissolved oxygen, pH, and total manganese following oxidation of "artificial hypolimnetic water"

removal mechanism (Stumm and Morgan 1970). To test this hypothesis, a 1-g portion of granular manganese dioxide was added to a 4-l beaker containing artificial hypolimnetic water. As in previous experiments, the water was stirred with a magnetic stirrer. Samples taken within the first 2 hr following the introduction of the manganese dioxide showed that reduced manganese was being removed at a much faster rate compared

to water without the manganese dioxide. Subsequently, a similar experiment was performed substituting gravels taken from the Little Missouri River downstream from Narrows Dam. The gravels were black and obviously coated with the hydrous oxide of manganese. Figure 14 shows the results of an experiment conducted with and without the gravels. The accelerated removal of manganese is obvious. The action of the gravels on the removal of reduced manganese from the water was further confirmed by adding manganese chloride to distilled water and observing the subsequent changes in manganese concentration both with and without the gravels being present. Again, relatively fast removal rates on the order of 0.5 mg/l/hr were observed when the coated gravels were present.

38. Since the gravels coated with the hydrous oxide of manganese appear to have a significant effect on the removal of manganese from water, the decision was made to determine if these gravels could play an active part in the removal of other trace metals. Numerous investigators have noted that cobalt, copper, and zinc are absorbed onto manganese oxide coatings existing in soils and streams (Gray and Malati 1979, Hasany and Qureshi 1981).

39. A 3-l portion of distilled water was spiked with 100 ug/l of the following metals: copper, cobalt, zinc, lead, silver, and nickel and 10 ug/l of cadmium. Ten hydrous oxide-coated gravels ranging in size from 1 to 2 cm were placed in a 4-l beaker with the solution containing the metals. This solution was sampled periodically for a period of approximately 4 hr. The samples were acidified with nitric acid, and the concentration of each of the metals was determined using the graphite furnace atomic absorption technique. The results of this experiment are illustrated in Figure 15. A decrease in concentration of all of the metals was observed. The removal of these metals from solution appears to follow first-order kinetics with half-time for removal ranging from 95 min for nickel to 20 min for lead.

40. Other investigators have suggested that the involvement of manganese oxide-coated gravels in the removal of reduced manganese from solution may involve a bacterial catalyzed interaction (Meyers 1961). The affinity of the gravels for such a large number of metals suggests

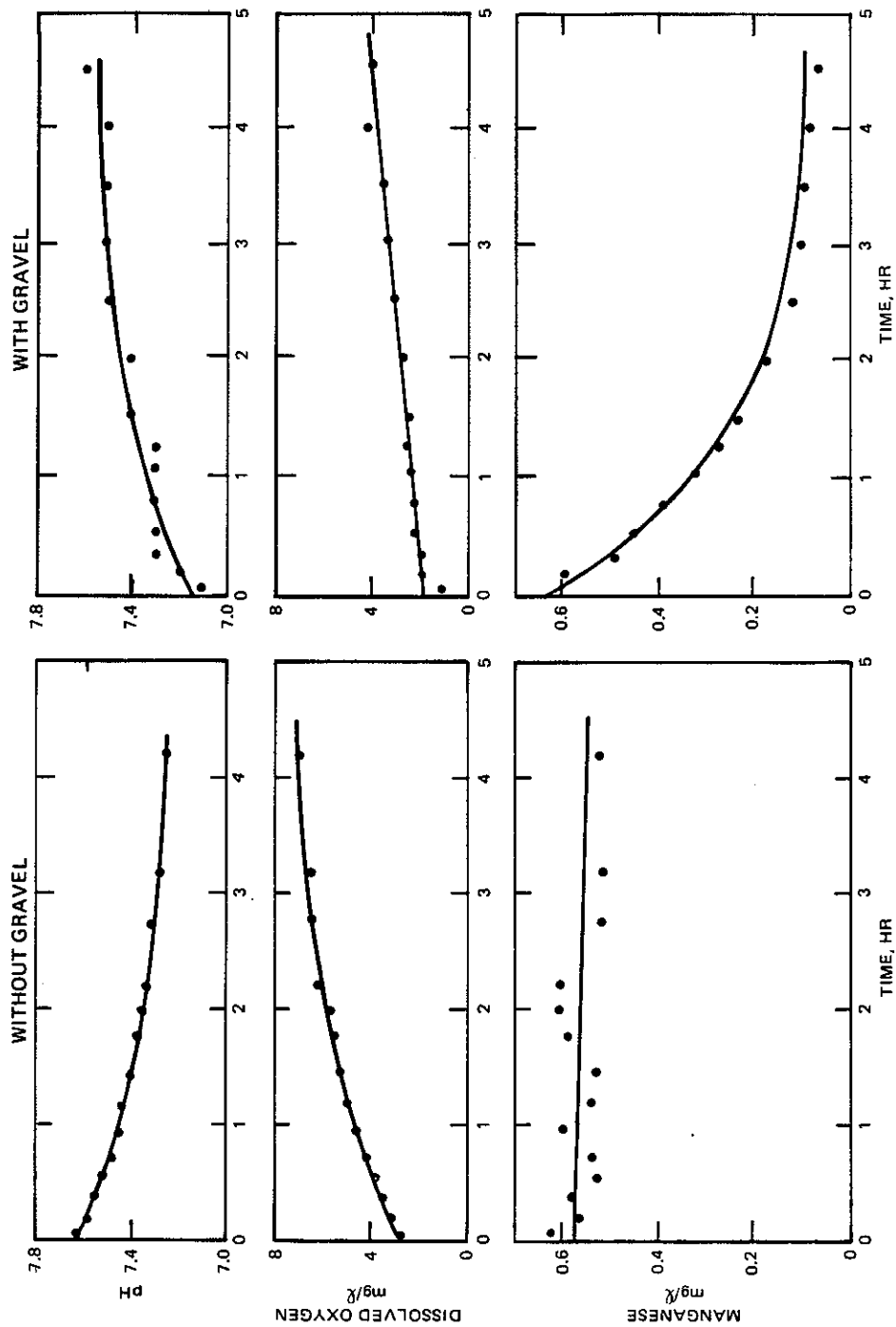


Figure 14. Dissolved oxygen, pH, and manganese in laboratory oxidation experiments using water taken from a depth of 20 m in Lake Greason on 16 November 1983. The experiment was done both with and without coated gravels

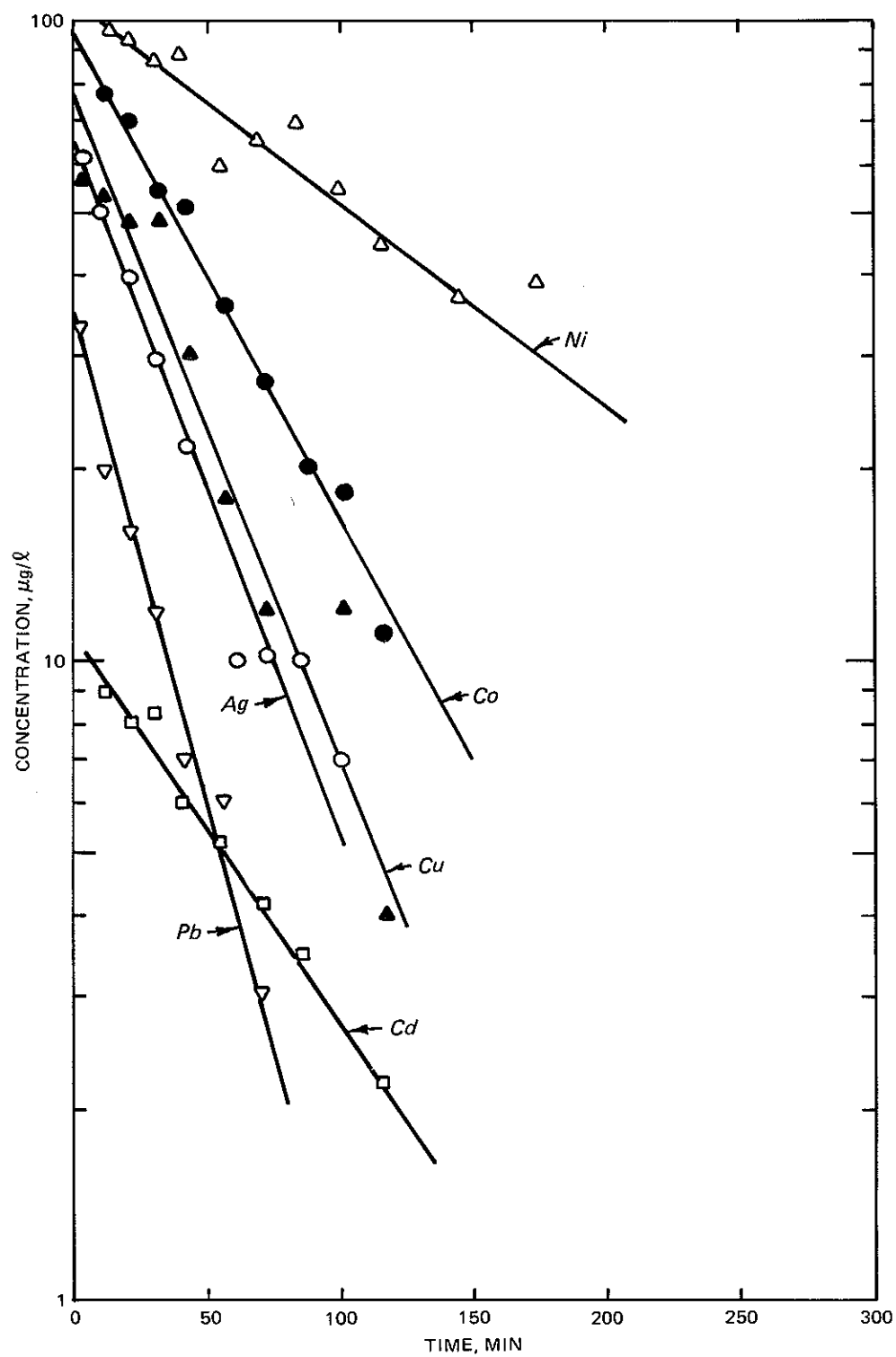


Figure 15. Concentration of selected trace metals in contact with gravels coated with hydrous oxide of manganese

that it is more likely that the removal involves direct absorption. It seems unlikely that bacterial action could be so similar for such a wide variety of metals. Since absorption of metals onto hydrous oxides has been treated by numerous investigators as a straightforward absorption process (Gray and Malati 1979), there is no need to involve a biological mechanism.

41. The abundance of hydrous oxide-coated gravels in the tailwater of Narrows Dam clearly impacts the chemistry of this tailwater. This study suggests that these gravels are an important factor in the removal of manganese from streams receiving water from anoxic regions of a reservoir. The findings further suggest that the presence of these gravels is an important factor in the ultimate fate of other trace metals which may be introduced into these tailwater environments. Should the nature of a tailwater stream be such that there are no gravel or rock surfaces on which coatings of hydrous manganese oxides could be maintained, it would be expected that reduced manganese as well as other trace metals might be transported much further downstream. The possibility of the release of trace metals from absorption sites under more acidic conditions should also be considered.

42. It would appear that the coatings of the hydrous oxides of manganese are maintained by the periodic release of reduced manganese into the tailwater. Once this situation is established, removal rates of manganese can be expected to increase. In tailwaters where manganese has been a problem, particularly for municipal and industrial users, the maximizing of contact with the coated gravels should be explored as one way to improve downstream water quality.

References

- American Public Health Association. 1980. Standard Methods for the Examination of Water and Wastewater, 15th ed., APHA-AWWA-WPCF, Washington, DC.
- Delfino, Joseph J., and Lee, G. Fred. 1968. "Chemistry of Manganese in Lake Mendota, Wisconsin," Environmental Science and Technology, Vol 1, p 1094.
- Garrels, Robert M., and Christ, Charles L. 1965. Solutions, Minerals, and Equilibrium, Harper and Row, New York.
- Gordon, John A. 1983. "Iron, Manganese and Sulfide Mechanics in Streams and Lakes--A Literature Review," Department of Civil Engineering, Tennessee Technological University, Cookeville, Tenn.
- _____. 1984. "Iron, Manganese and Sulfides in the Duck River Below Normandy Dam," Report TTU-CE-82-2, Tennessee Technological University, Cookeville, Tenn.
- Gordon, John A., and Bonner, W. P. 1983. "Iron, Manganese and Sulfides in the Duck River Below Normandy Dam," prepared for Tennessee Valley Authority by Department of Civil Engineering, Tennessee Technological University, Cookeville, Tenn.
- Gray, Malcom J., and Malati, Mounir A. 1979. "Absorption from Aqueous Solution by Delta-Manganese Dioxide; Absorption of Some Heavy Metal Cations," Journal of Chemical Technology and Biotechnology, Vol 29, pp 135-144.
- Hasany, Syed Moosa, and Qureshi, Mudassar Ahmed. 1981. "Absorption Studies of Cobalt (II) on Manganese Dioxide from Aqueous Solution," International Journal of Applied Radiation and Isotopes, Vol 32, pp 747-752.
- Ingols, Robert S. 1957. "Pollutional Effects of Hydraulic Power Generation," Sewage and Industrial Wastes, Vol 29, pp 292-297.
- Meyers, H. C. 1961. "Manganese Deposits in Western Reservoirs and Distribution Systems," Journal of the American Water Works Association, pp 579-588.
- Nix, J. 1979. "Physical, Chemical and Bacteriological Water Quality Monitoring at Lakes DeGray, Ouachita, and Greeson," prepared by Ouachita Baptist University, Arkadelphia, Ark., for US Army Engineer District, Vicksburg.
- _____. 1981. "Contribution of Hypolimnetic Water on Metalimnetic Dissolved Oxygen Minima in a Reservoir," Water Resources Research, Vol 17, pp 329-332.
- _____. 1985. "Arkansas Lakes Interim Study, Final Report," prepared by Ouachita Baptist University, Arkadelphia, Ark., for US Army Engineer District, Vicksburg, Vicksburg, Miss.

Stumm, Werner, and Morgan, James J. 1970. Aquatic Chemistry, John Wiley and Sons, New York.

US Environmental Protection Agency. 1976. "Manual of Methods for Chemical Analysis of Water and Wastes," EPA Technology Transfer, Cincinnati, Ohio.

_____. 1979. "Methods for the Analysis of Water and Wastes," EPA Technology Transfer, Cincinnati, Ohio.

Walburg, Charles H., et al. 1981. "Water Quality, Macroinvertebrates, and Fisheries in Tailwaters and Related Streams," Technical Report E-81-8, prepared by US Fish and Wildlife Service, Bowling Green, Ky., for US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Wilson, D. E. 1980. "Surface and Complexation Effects on the Rate of Mn(II) Oxidation in Natural Waters," Geochimica et Cosmochimica Acta, Vol 44, p 1311.

Appendix A: Field Determination of Hydrogen Sulfide in Water

1. The method described for the determination of sulfide in the field is not new. Rather, it is a combination of methods that the authors have found to be successful for studies of water from the hypolimnion of reservoirs, as well as the tailwaters of dams that release hypolimnetic water. This discussion of the method is not intended to be a formal development of an analytical method. The authors have simply combined some proven techniques into a procedure that seems to work well for relatively low concentrations of hydrogen sulfide. Although the method requires the transport of some small equipment into the field, it is easily carried out under field conditions.

2. Hydrogen sulfide is usually determined using the titrimetric procedure described in USEPA (1976), "Methods for the Analysis of Water and Wastes." Two problems are encountered with this method: (a) a lack of sensitivity and (b) preservation techniques that may be questionable at low concentrations. Use of the methylene Blue method described in the 1976 USEPA manual can overcome the problem of sensitivity but still requires sample preservation.

3. Sulfide in the aquatic environment is a rather illusive material. It is easily lost by degassing and can be oxidized to sulfate. Thus, the manipulation of the sample and the exclusion of air become very important. Hydrogen sulfide usually develops in response to low redox conditions caused by a depletion of DO. When DO is introduced into anaerobic water containing hydrogen sulfide, the reduced sulfur species and oxygen can coexist for a short period of time. It is not clear if the usual sample preservation techniques (coprecipitation of zinc sulfide with zinc hydroxide) stops the oxidation process or if it can continue after the addition of the preservative. With such doubts about the integrity of a "preserved" sample, it becomes obvious that a field determination would be highly desirable in order to obtain meaningful data, especially at low concentrations.

4. The direct use of a sulfide selective electrode is precluded due to the fact that iron is often present in anaerobic water which

contains hydrogen sulfide. The conditions required for operation of the electrode include bringing the sample to a high pH by the addition of a strong base. At high pH, the hydrogen sulfide is converted almost totally to the sulfide ion, which then can react with iron (as well as other metals) to form insoluble sulfides. In order to use a selective iron electrode, the sulfide species must be removed from metals that would precipitate as sulfides under strongly basic conditions.

5. Hydrogen sulfide is easily stripped from acidic solution with nitrogen gas. The redissolving of the hydrogen sulfide is accomplished by exposing the gas stream to a strongly basic solution. The stripping followed by redissolving in a basic solution results in a solution that is free of interferences, thus allowing the effective use of the sulfide electrode. In addition to the removal of interfering substances, the stripping-redissolving step serves to concentrate the sulfide, which extends the effective range of the electrode.

6. A procedure for the determination of sulfide is described which is easily adaptable to use under field conditions. Concentrations of sulfide on the order of 0.01 mg/l are easily detectable.

Materials

7. All reagents used were analytical-grade chemicals. The sulfide ion sensi-electrode was an Orion Model 94-16, used in conjunction with an Orion Model 231 digital pH meter. The pH meter was used in the millivolt mode which was sensitive to ± 1 mV. The apparatus that was used for the degassing of the samples is shown in Figure A1. This apparatus is easily constructed from rubber tubing, glass tubing, rubber stoppers, sintered glass gas dispersion tubes, and readily available bottles and flasks.

8. All samples were secured using a van Dorn type water sampler with a rubber tube attached to the lower port. Sample bottles were 1.0-l polyethylene with polypropylene tops (narrow mouths). A small lecture bottle of compressed nitrogen was found to be most convenient to transport into the field.

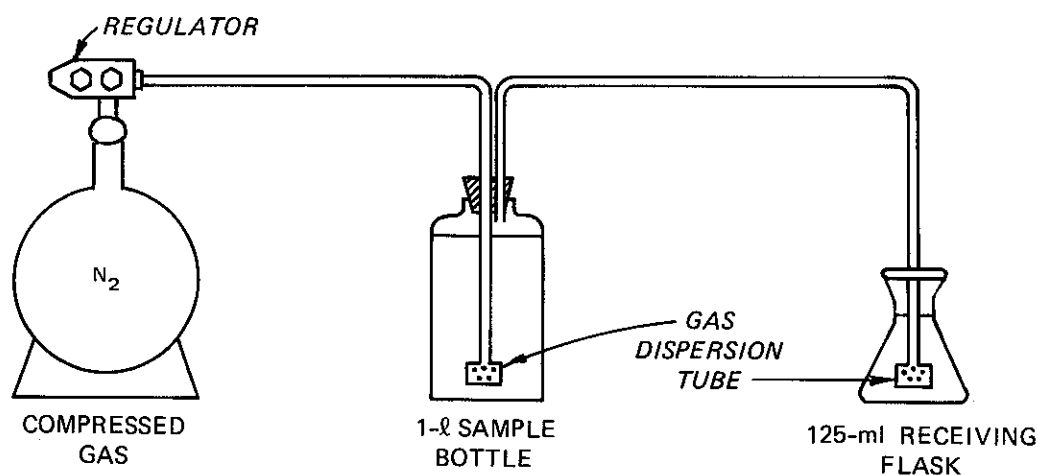


Figure A1. Degassing apparatus

9. The following solutions were prepared:

- a. Sodium sulfide solution. Dissolve approximately 7.9 g of $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ in a small amount of distilled water, then dilute to approximately 1 l. An appropriate dilution of this solution was standardized using the titrimetric procedure described in the EPA Manual (1979). This standardization was done on the same day that it was to be used.
- b. 100 mg/L sulfide standard. After standardization of the sodium sulfide solution, an appropriate volume was diluted to produce 200 ml of a 100 mg/l solution. This solution must be made on the same day of use.
- c. 9 molar H_2SO_4 . Add 50 ml of concentrated H_2SO_4 to 50 ml of water with constant stirring and cooling of the container. MAKE ADDITION SLOWLY AND WITH CAUTION.
- d. Antioxidant. Dissolve 80 g of NaOH in approximately 100 ml of water, then add 130 g of ascorbic acid. Dilute the resulting solution to 500 ml.

Procedure

10. Samples were obtained using a 2.0-l van Dorn type sampler. The rubber tube connected to the lower port of the sampler was placed in the bottom of a 1.0-l sample bottle and the bottle was overfilled by approximately 500 ml. The tube was removed and the bottle was capped with a minimum of trapped air. Sample analysis was begun within 10 min after the time of collection.

11. The plastic cap was removed from the sample bottle. A small air pocket was created in the bottle by pouring out approximately 25 ml of the water. The gas dispersion tube was inserted into the bottle and the rubber stopper firmly pushed into the bottle top.

12. A 3.0-ml aliquot of the antioxidant was added to 100 ml of distilled water and placed in a 125-ml Erlenmeyer flask. The second gas dispersion tube was placed in the Erlenmeyer flask. After the apparatus was secured, 1.0 ml of the 9 molar sulfuric acid was added to the sample. The rubber stopper was quickly reinserted into the bottle after the addition of the acid. The nitrogen flow was adjusted to approximately 1.0 l/min. The stripping procedure was continued for 2.5 min.

13. Immediately after the flow of nitrogen stopped, the sulfide electrode was immersed in the flask and the initial millivolt reading was obtained while gently hand-stirring the flask. After the initial reading had been obtained, a 1.0-ml aliquot of the 100 mg/l sulfide solution was pipetted into the solution. As before, with gentle hand-stirring, the final reading was obtained. A ΔmV was calculated by subtracting the final reading from the initial reading.

14. Standardization of the procedure was accomplished by preparing 1.0 l of a series of solutions of known sulfide concentration by dilution of appropriate aliquots of the 100 mg/l standard. The concentrations of 0.01 mg/l, 0.1 mg/l, and 1.0 mg/l were found to provide satisfactory calibration. The ΔmV values determined for each of these standards were plotted against their respective concentrations on a semilog graph. The resulting straight line was used to convert the ΔmV values obtained for samples into concentrations of sulfide. A typical calibration curve is shown in Figure A2. The volume of the original sample was measured with a graduated cylinder. The sulfide concentration obtained from the calibration graph was corrected for actual sample size.

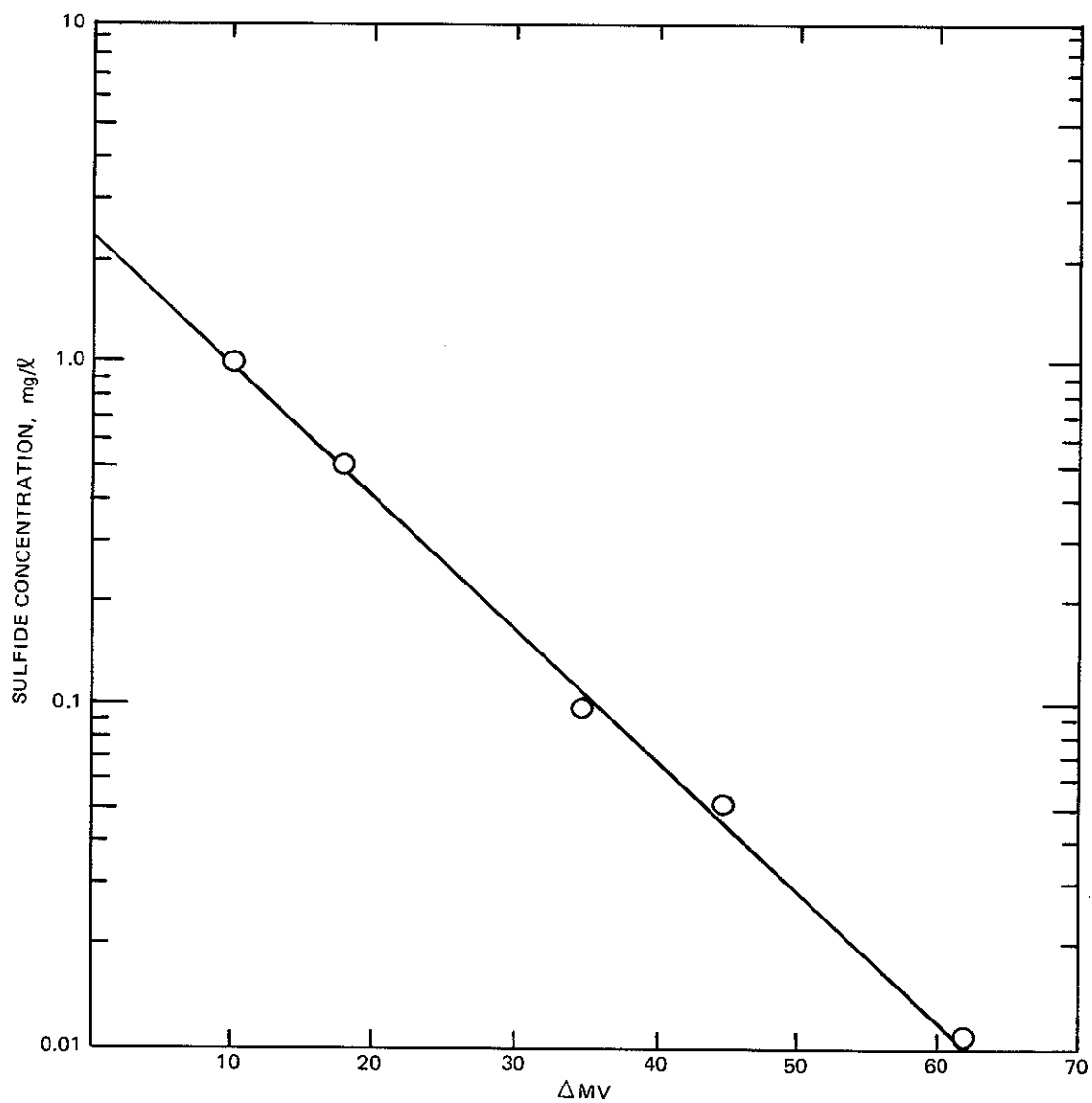


Figure A2. Typical calibration curve

Appendix B: Data Listings, Lake Greeson and Little
Missouri River, May-December 1983

LAKE GREESON
G - 1

DATE 5-23-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	22.7	8.7	6.7	17
1	22.6	8.7	6.7	18
2	22.5	8.6	6.7	18
3	20.9	8.8	6.8	18
4	20.4	8.6	6.6	17
5	19.8	8.0	6.6	18
6	18.8	7.4	6.4	18
7	18.0	7.2	6.3	17
8	17.8	7.1	6.3	17
9	17.6	7.2	6.2	17
10	17.4	7.2	6.0	18
11	17.0	7.2	6.0	18
12	16.6	7.2	6.0	18
13	15.7	7.2	5.9	18
14	15.2	7.1	5.8	17
15	14.1	7.2	5.8	18
16	13.5	7.1	5.8	18
17	13.4	7.0	5.8	18
18	12.3	7.1	5.7	18
19	11.9	7.1	5.6	17
20	11.7	7.1	5.6	17
21	11.4	7.1	5.6	17
22	11.0	7.0	5.5	18
23	10.4	7.0	5.5	16
24	10.0	7.0	5.5	17
25	9.6	6.8	5.4	17
26	9.1	6.6	5.4	17
27	8.4	6.4	5.4	17
28	8.1	6.2	5.3	16
29	7.8	6.1	5.3	16
30	7.5	6.1	5.3	16

5-23-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
31	7.4	6.2	5.3	16
32	7.3	6.2	5.3	16
33	7.2	6.3	5.3	16
34	7.0	6.4	5.3	15
35	6.9	6.6	5.3	15
36	6.8	6.4	5.3	15
37	6.8	6.1	5.3	15
38	6.7	6.0	5.3	17
39	6.7	5.9	5.3	17
40	6.7	5.9	5.4	17
41	6.6	5.8	5.4	17
42	6.6	5.6	5.4	17
43	6.6	5.4	5.4	17
44	6.6	5.4	5.4	17
45	6.6	5.2	5.4	17
46				
47				
48				
49				
50				

LAKE GREESON

G - 1

Date 5-23-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	6	3.5		2.0	6.1	3.2	.015	
4	6	1.2		2.2	6.5	3.3	.024	.040
10	6	4.8		1.8	12.	4.4	.015	.024
13								
15	7	4.6		2.2	5.9	4.7	.018	.008
25	7	5.4		2.0	4.8	4.8	.018	.009
41.7								
44		8.6		1.5	11.	5.2	.012	.006

B3

LAKE GREESON

Date 5-23-83

G - 1

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0		0.5	0.05		5.9	1.4	2.4	0.8
4	.046	0.7	0.09		6.3	1.6	2.3	0.8
10	.002	0.3	0.06		5.8	1.4	2.3	0.8
13								
15	.002	0.8	0.07		5.6	1.6	2.4	0.8
25	.005	1.0	0.07		6.8	1.6	2.4	0.8
41.7								
44	.004	0.6	0.04		5.9	1.5	2.7	0.8

LAKE GREESON

G - 1

Date 5-23-83

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	0.9	.39		.014	
4	1.0	.73	.06	.022	.008
10	1.0	1.02	.01	.016	.025
13					
15	1.0	.89	.01	.023	.004
25	1.1	.35		.023	
41.7					
44	1.1	.94	.09	.196	.200

LAKE GREESON
G - 1

DATE 6-29-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	26.8	8.4	6.7	15
1	26.9	8.3	6.7	15
2	26.8	8.2	6.9	15
3	26.2	8.0	6.9	16
4	25.6	8.1	6.9	16
5	22.9	5.4	6.6	16
6	20.5	2.8	6.3	15
7	19.3	2.9	6.0	15
8	18.8	3.0	5.9	15
9	18.5	3.3	5.8	14
10	17.8	4.1	5.6	14
11	17.5	4.3	5.7	14
12	16.9	4.8	5.7	13
13	16.6	5.2	5.7	13
14	16.2	5.5	5.6	13
15	15.8	5.3	5.6	13
16	15.3	5.5	5.6	13
17	14.6	5.9	5.7	14
18	13.8	6.1	5.6	13
19	13.0	6.1	5.6	13
20	12.2	6.1	5.6	13
21	11.9	6.1	5.5	13
22	11.3	6.1	5.5	12
23	10.8	6.2	5.5	12
24	10.3	6.1	5.5	12
25	9.9	5.8	5.5	13
26	9.1	5.5	5.5	11
27	8.4	5.5	5.4	12
28	8.0	5.5	5.4	12
29	7.7	5.9	5.3	12
30	7.4	6.2	5.3	10

6-29-83

Depth	Temperature (°C)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.2	6.1	5.3	10
32	7.1	6.1	5.3	10
33	7.1	6.3	5.2	10
34	6.9	5.5	5.2	10
35	6.8	5.8	5.2	10
36	6.8	5.7	5.2	10
37	6.7	5.5	5.2	11
38	6.7	5.2	5.2	11
39	6.7	5.0	5.2	11
40	6.6	4.5	5.2	11
41	6.6	3.9	5.2	11
42	6.6	3.4	5.2	12
43	6.6	2.4	5.2	14
44	6.7	0.8	5.3	17
45				
46				
47				
48				
49				
50				

LAKE GREESON

G - 1

Date 6-29-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	8	2.3	.000	2.0	5.1	0.5	.008	.006
4	9	1.8	.001	1.7	4.1	0.7	.007	.013
10	8	9.2	.000	1.7	7.5	2.8	.005	.014
13								
15	7	7.5	.000	1.5	6.7	2.8	.005	.015
25	9	7.0	.000	1.7	4.0	3.0	.005	.005
41.7								
44								
43.8	10	11.7	.004	1.0	21.0	3.3	.025	.018

B8

LAKE GREESEON

G - 1

Date 6-29-83

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.002	.48	.04	.14	7.5	1.4	1.6	0.7
4	.007	.96	.05	.10	8.1	1.5	1.8	0.8
10	.008	.35	.05	.15	7.4	1.4	1.7	0.7
13								
15	.012	.40	.04	.17	7.8	1.4	1.7	0.7
25	.005	.22	.03	.29	5.6	1.4	3.4	0.8
41.7								
44								
43.8	.025	.46	.06	.25	7.4	1.3	1.9	0.8

B9

Date 6-29-83

LAKE GREESON
G - 1

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	0.8	.31	.09	.029	.012
4	0.8	.37	.05	.020	.014
10	0.9	.51	.04	.062	.021
13					
15	0.9	.43	.06	.027	.021
25	0.9	.38	.05	.120	.102
41.7					
44					
43.8	1.0	1.68	.22	.700	.560

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

DATE 7-25-83

Station Designation	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
A	17.8	2.3	5.6	20
B	18.1	2.7	5.6	18
C	18.2	4.2	5.8	19
D	18.7	5.0	5.6	19
E	19.0	5.0	5.7	19
F	18.2	5.9	5.7	21
G	18.6	6.4	5.8	20
H				

B11

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 7/25-26/83

Station Designation	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
A	7.0	10.6		1.8	7.7		.028	.035
B	7.1	10.1		1.9	7.4		.032	.011
C	6.0	9.3		1.9	9.1		.055	.007
D	5.6	9.0		1.8	11.		.026	.017
E	8.0	8.6		1.7	8.8		.052	.020
F								
G	3.1	7.7		2.3	9.6		.036	.029
H	6.1	7.8		2.3	10.		.048	.024

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 7/25-26/83

Station Designation	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
A	.011	.17	.02	.18	8.9	1.4	1.9	0.8
B	.009	.21	.03	.17	6.9	1.5	1.9	0.8
C	.013	.19	.04	.18	8.0	1.4	1.9	0.8
D	.010	.18	.03	.20	9.6	1.5	2.0	0.8
E	.009	.22	.02	.20	8.8	1.5	2.0	0.8
F								
G	.006	.15	.04	.20	9.4	1.6	2.3	0.9
H	.009	.23	.04	.17	10.4	1.6	2.3	0.9

B13

Date 7/25-26/83

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Station Designation	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
A	0.9	.41	.08	.30	.24
B	1.0	.30	.08	.31	.28
C	1.0	.44	.10	.37	.22
D	1.0	.75	.09	.28	.22
E	1.0	.40	.18	.30	.23
F					
G	1.0	.61	.33	.21	.09
H	1.0	.52	.59	.16	.02

LAKE GREESON
G - 1

DATE 8-1-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	32.4	8.1	7.3	19
1	32.0	8.0	7.3	19
2	31.8	7.6	7.4	19
3	31.6	7.4	7.4	19
4	30.4	7.7	7.5	20
5	26.9	3.6	7.3	19
6	25.6	1.4	6.9	20
7	24.2	1.0	6.7	19
8	23.0	1.1	6.5	20
9	22.3	1.2	6.4	20
10	21.8	1.4	6.3	19
11	21.2	1.2	6.2	19
12	20.6	0.9	6.1	20
13	19.8	0.6	6.0	20
14	18.8	0.7	6.0	20
15	17.8	1.3	5.9	21
16	17.2	1.2	5.8	21
17	16.5	1.2	5.8	21
18	15.8	1.2	5.8	22
19	15.1	1.4	5.7	22
20	14.4	1.8	5.7	22
21	13.3	2.1	5.7	22
22	12.1	2.4	5.7	21
23	11.0	2.7	5.7	22
24	10.0	2.8	5.7	22
25	9.1	3.3	5.6	20
26	8.6	3.8	5.6	19
27	8.1	4.3	5.6	17
28	7.9	4.5	5.6	18
29	7.7	4.6	5.6	16
30	7.5	4.8	5.6	16

8-1-83

Depth	Temperature (°C)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.4	4.9	5.5	16
32	7.2	4.4	5.6	16
33	7.2	4.5	5.5	16
34	7.1	4.6	5.5	16
35	7.0	4.6	5.4	16
36	7.0	4.0	5.5	16
37	6.9	3.7	5.4	16
38	6.9	3.8	5.4	16
39	6.9	3.1	5.4	16
40	6.9	0.9	5.5	18
41	6.9	0.5	5.4	22
42	6.9	0.3	5.5	24
43	7.0	0.3	5.4	39
44				
45				
46				
47				
48				
49				
50				

LAKE GREESON
G - 1

Date 8-1-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	9.0	0.4	0.0	1.5	3.3	0.9	.015	.006
4	11.0	0.5	0.0	2.0	3.9	1.3	.012	.003
10	8.0	16.0	0.0	1.5	6.9	4.4	.013	.003
13	9.0	17.4	0.0	1.5	6.1	4.9	.020	.005
15	10.0	16.1	0.0	1.7	5.6	5.2	.006	.001
25	9.0	12.9	0.0	1.7	5.3	5.5	.008	.008
41.7								
44								
42.3	3.0	20.7	0.0	0.0	42.5	6.4	.041	.004

B17

LAKE GREESON
G - 1

8-1-83

Date

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.014	.33	.06	.06	8.3	1.2	1.8	0.8
4	.004	.33	.02	.14	8.2	1.2	1.8	0.8
10	.005	.32	.04	.12	8.6	1.1	2.0	0.7
13	.009	.21	.05	.14	7.6	1.2	2.1	0.8
15	.004	.23	.03	.17	6.6	1.2	2.1	0.8
25	.005	.16	.04	.30	6.1	1.2	2.1	0.8
41.7								
44								
42.3	.007	.67	.29	.12	8.4	1.2	2.5	1.0

B18

LAKE GREESON

G - 1

Date 8-1-83

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	0.8	.00	.06	.01	.03
4	0.8	.00	.01	.01	.02
10	0.9	.26	.07	.05	.05
13	0.9	.35	.15	.11	.10
15	0.9	.37	.11	.19	.16
25	0.9	.50	.25	.26	.25
41.7					
44					
42.3	1.0	.55	.25	.06	1.55

B19

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

DATE 8-9-83

Station Designation	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
A	18.9	1.7	5.4	20
B	19.1	2.5	5.4	20
C	19.2	2.9	5.3	19
D	19.7	4.4	5.4	20
E	19.8	4.4	5.5	20
F	20.5	6.3	6.6	21
G				
H				

B20

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 8-9-83

Station Designation	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/l.)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
A	7.9	10.9		1.0	3.9	5.1	.015	.009
B	9.0	12.2		1.3	4.2	5.4	.010	.012
C	8.5	10.7		1.1	2.2	5.3	1.14	.014
D	8.8	10.2		1.6	3.6	5.3	.012	.016
E	8.8	9.3		2.1	4.3	5.4	.013	.015
F	15.6	7.9		1.3	4.6	5.1	.011	.007
G								
H								

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 8-9-83

Station Designation	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
A	.007	.46	.05	.28	9.5	1.3	1.6	0.9
B	.005	.31	.04	.19	8.4	1.8	1.7	0.9
C	.004	.40	.07	.32	8.5	1.5	1.8	0.9
D	.007	.39	.06	.33	7.5	1.5	1.6	0.9
E	.008	.40	.06	.33	7.4	1.4	1.5	0.9
F	.004	.48	.12	.19	8.1	1.5	1.7	0.9
G								
H								

Date 8-9-83

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Station Designation	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
A	1.0	.34	.13	.25	.25
B	1.2	.41	.12	.26	.24
C	1.1	.37	.32	.23	.23
D	1.1	.32	.14	.19	.19
E	1.0	.37	.23	.20	.23
F	1.1	.34	.06	.16	.13
G					
H					

LAKE GREESON
G - 1

DATE 8-16-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	30.6	6.9	6.9	19
1	30.6	7.1	6.9	19
2	30.6	7.2	6.9	19
3	30.6	6.9	7.0	19
4	30.6	7.1	7.0	19
5	29.6	4.4	7.1	19
6	27.1	1.7	6.7	20
7	25.2	1.3	6.6	20
8	23.7	1.2	6.5	20
9	22.4	1.4	6.4	20
10	22.0	1.2	6.3	19
11	21.4	1.1	6.2	19
12	20.9	1.1	6.1	19
13	20.2	1.1	6.1	21
14	19.9	1.1	6.0	21
15	18.4	1.1	6.0	21
16	17.6	1.2	5.9	21
17	16.8	1.4	5.9	21
18	16.1	1.6	5.9	22
19	15.4	1.6	5.9	22
20	14.5	1.8	5.8	22
21	13.3	2.3	5.8	23
22	12.4	2.7	5.8	22
23	11.0	3.0	5.8	22
24	10.0	3.1	5.8	21
25	9.3	3.5	5.7	20
26	8.8	3.9	5.7	19
27	8.3	4.3	5.6	19
28	8.1	4.5	5.6	17
29	7.8	4.7	5.5	18
30	7.7	4.8	5.5	16

8-16-83

Depth	Temperature ($^{\circ}\text{C}$)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.5	4.7	5.5	16
32	7.4	4.5	5.5	16
33	7.3	4.4	5.5	16
34	7.2	4.3	5.5	16
35	7.2	4.0	5.5	16
36	7.1	3.6	5.5	16
37	7.1	2.4	5.5	18
38	7.0	0.8	5.5	19
39	7.0	0.6	5.4	21
40	7.1	0.6	5.4	24
41	7.1	0.5	5.4	31
42	7.2	0.5	5.4	49
43				
44				
45				
46				
47				
48				
49				
50				

LAKE GREESON
G - 1

Date 8-16-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	7	.9	0	3.0	2.6	1.1	.037	.014
4	8	.4	0	1.9	2.7	1.2	.016	.029
10	8	12.1	0	0.4	5.7	5.1	.012	.024
13	9	15.8	0	1.9	6.2	5.4	.016	.013
15	9	13.2	0	2.3	5.1	5.8	.031	.032
25	8	11.1	0	2.4	6.8	6.2	.035	.037
41.7	28	22.5	0	0	57.	8.3	.076	.048
44								

LAKE GREESEON

G - 1

Date 8-16-83

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.000	.43	.03		7.1	1.4	1.7	0.8
4	.010	.24	.02		6.7	1.3	1.3	0.8
10	.002	.15	.02		8.4	1.2	1.6	0.9
13	.002	.17	.02		7.2	1.2	1.6	0.9
15	.004	.18	.03		6.5	1.3	1.6	0.9
25	.005	.14	.03		6.2	1.3	2.1	0.9
41.7	.021	.76	.58		11.1	1.3	2.6	1.3
44								

LAKE GREESON
G - 1

Date 8-16-83

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	0.9	.02	.00	.01	.01
4	0.9	.03	.05	.01	.02
10	1.0	.27	.14	.09	.10
13	1.0	.40	.21	.19	.18
15	1.0	.45	.24	.25	.23
25	1.0	.58	.13	.37	.32
41.7	1.1	8.45	.14	309	.02
44					

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

DATE 8-17-83

Station Designation	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
A	19.6	1.3	6.1	36
B	19.6	2.0	5.7	33
C	19.4	3.1	5.6	32
D	19.8	4.2	5.6	31
E	20.0	4.6	5.5	30
F	21.9	7.1	5.5	29
G	21.8	7.4	5.6	32
H	21.7	7.3	5.7	33

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 8-17-83

Station Designation	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
A	8.6	13.9		1.2	5.1	5.4	.017	.012
B	8.4	11.8		1.0	8.3	5.5	.014	.013
C	7.0	10.9		0.5	6.4	5.4	.014	.012
D	7.8	8.8		0.9	4.8	5.5	.012	.016
E	7.0	8.5		0.7	4.6	5.5	.009	.011
F	6.2	4.8		0.8	6.2	5.5	.012	.014
G	6.7	5.4		0.9	6.4	5.4	.010	.012
H	5.1	3.8		0.9	6.7	5.4	.014	.018

Date 8-17-83

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Station Designation	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
A	.006	.93	.09	.16	8.9	1.5	1.7	0.9
B	.003	.38	.10	.15	7.2	1.3	1.7	0.9
C	.005	.86	.13	.16	9.4	1.5	1.9	0.9
D	.003	.17	.03	.14	6.9	1.3	1.8	0.9
E	.004	.36	.05	.13	7.4	1.3	1.6	0.9
F	.003	.50	.08	.13	9.6	1.4	1.8	0.9
G	.004	.50	.07	.16	7.9	1.4	1.8	0.9
H	.005	.39	.06	.19	7.6	1.4	1.8	1.0

Date 8-17-83

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Station Designation	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
A	1.2	.40	.23	.29	.26
B	1.0	.37	.18	.27	.25
C	1.1	.33	.16	.27	.22
D	1.0	.19	.06	.24	.21
E	1.0	.24	.11	.23	.21
F	1.0	.33	.12	.14	.10
G	1.0	.40	.24	.10	.09
H	1.0	.47	.14	.10	.08

LAKE GREESON
G - 1

DATE 8-29-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	29.8	6.9	7.2	23
1	29.8	6.8	7.2	23
2	29.7	6.8	7.3	23
3	29.7	6.8	7.3	22
4	29.6	6.8	7.3	22
5	29.3	5.8	7.3	22
6	27.8	2.6	7.0	23
7	24.7	1.4	6.8	23
8	23.2	1.4	6.6	24
9	22.1	1.3	6.4	24
10	21.2	1.3	6.3	24
11	20.6	1.3	6.2	24
12	19.8	1.2	6.1	24
13	19.2	1.1	6.0	25
14	18.5	0.8	5.9	25
15	17.8	0.8	5.8	25
16	16.8	0.7	5.9	26
17	15.9	0.7	5.8	27
18	15.0	0.7	5.8	27
19	14.0	0.9	5.7	26
20	12.8	1.4	5.7	26
21	11.5	1.8	5.7	25
22	10.8	1.9	5.6	24
23	9.8	2.1	5.6	24
24	9.2	2.5	5.6	21
25	8.5	3.2	5.5	22
26	8.1	3.8	5.5	20
27	7.9	4.1	5.4	20
28	7.7	4.3	5.4	19
29	7.5	4.4	5.4	19
30	7.3	4.4	5.4	19

8-20-83

Depth	Temperature (°C)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.2	4.4	5.4	19
32	7.1	3.8	5.4	19
33	7.0	3.8	5.4	19
34	6.9	3.4	5.4	19
35	6.8	2.7	5.4	19
36	6.8	1.5	5.4	21
37	6.8	0.6	5.4	24
38	6.8	0.5	5.3	25
39	6.8	0.5	5.3	33
40	6.8	0.5	5.3	43
41	6.9	0.5	5.3	70
42				
43				
44				
45				
46				
47				
48				
49				
50				

LAKE GREESON

G - 1

Date 8-29-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	9	.7		2.7	2.4	1.3	.003	.003
4	8	1.1		2.7	2.2	1.3	.007	.001
10	8	16.3		1.0	3.3	4.3	.008	.000
13								
15	10	16.6		0.9	5.9	5.4	.007	.003
17	10	17.2		0.8	7.0	6.0	.010	.003
25	9	11.9		0.8	6.2	5.8	.012	.002
40.9	39	16.8	.006	0.0	41.	8.2	.072	.061
41.7								
44								

B35

8-29-83

LAKE GREESON

G - 1

Date

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.002	.40	.03	.08	10.7	1.5	1.7	0.8
4	.002	.34	.03	.12	11.2	1.4	1.7	0.8
10	.001	.37	.03	.06	25.8	1.3	1.8	0.8
13								
15	.001	.35	.07	.05	10.3	1.4	1.9	0.9
17	.001	.34	.05	.20	12.3	1.5	2.1	0.9
25	.001	.24	.03	.37	9.6	1.4	1.9	0.8
40.9	.032	1.16	.90	.05	57.	1.5	2.9	1.1
41.7								
44								

LAKE GREESON

G - 1

Date 8-29-83

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	0.9	.02	.10	.01	.07
4	1.0	.00	.05	.02	.02
10	1.0	.21	.18	.15	.14
13					
15	1.0	.45	.18	.37	.36
17	1.0	.60	.18	.50	.59
25	1.0	.50	.46	.34	.35
40.9	1.2	11.0	6.30	3.42	3.20
41.7					
44					

B37

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

DATE 9-6-83

Station Designation	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
A	19.8	3.1	5.6	19
B	20.3	3.3	5.6	18
C	19.9	4.1	5.6	18
D	20.0	5.1	5.5	19
E	20.2	5.6	5.6	20
F	20.8	8.7	5.7	20
G	22.5			
H	21.0	6.9	5.8	22

B38

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 9/6-7/83

Station Designation	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
A	10	12.0		1.0	6.0	5.0	.002	.012
B	9	12.8		0.8	6.9	5.0		
C	11	11.0		1.0	6.7	5.0		
D	9	11.2		0.7	6.7	5.0		
E	9	11.1		0.9	7.0	4.9	.013	.038
F	8	9.8		1.1	6.7	4.8	.028	.025
G	8	6.8		1.0	6.3	5.0	.004	.002
H	17	5.3		0.8	7.1	5.2	.021	.005

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 9/6-7-/83

Station Designation	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
A	1.0	.70	.33	.39	.34
B	1.1	.65	.36	.32	.33
C	1.0	.71	.37	.32	.33
D	1.1	.64	.23	.29	.28
E	1.3	.65	.27	.28	.24
F	1.2	.56	.40	.18	.16
G	1.1	.45	.16	.05	.03
H	1.1	.44	.13	.02	.03

LAKE GREESON
G - 1

DATE 9-12-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	29.2	6.8	7.1	20
1	29.0	6.9	7.1	20
2	28.9	6.8	7.1	20
3	28.8	6.6	7.1	20
4	28.7	6.4	7.2	20
5	28.5	6.0	7.1	20
6	28.4	5.6	7.1	20
7	28.2	5.0	7.0	21
8	24.7	0.9	6.4	22
9	22.7	0.5	6.2	22
10	21.5	0.5	5.7	21
11	20.9	0.4	5.7	23
12	20.3	0.4	5.6	23
13	19.8	0.4	5.5	23
14	19.2	0.4	5.6	25
15	18.1	0.4	5.6	26
16	17.3	0.4	5.5	26
17	16.1	0.3	5.6	26
18	15.1	0.3	5.5	26
19	13.9	0.3	5.5	25
20	12.3	0.7	5.5	25
21	10.7	1.0	5.4	25
22	9.9	1.2	5.3	24
23	8.9	2.3	5.3	21
24	8.5	2.9	5.3	20
25	8.0	3.4	5.2	19
26	7.8	3.6	5.2	18
27	7.6	3.6	5.1	18
28	7.5	3.7	5.1	18
29	7.3	3.2	5.1	18
30	7.2	3.3	5.1	18

9-12-82

Depth	Temperature (°C)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.0	3.2	5.1	18
32	7.0	2.6	5.1	18
33	6.9	2.0	5.1	18
34	6.8	0.9	5.1	18
35	6.8	0.3	5.0	21
36	6.8	0.3	5.0	22
37	6.8	0.3	5.0	30
38	6.8	0.3	5.0	36
39	6.9	0.3	5.0	55
40	6.9	0.2	5.2	66
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				

LAKE GREESEON
G - 1

Date 9-12-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	7	4.4	0.00	3.3	3.3	1.3	.007	.005
4	8	3.3	0.00	2.7	4.7	1.0	.007	.006
10	9	16.3	0.05	0.8	5.3	3.3	.011	.007
13								
15	12	18	0.12	0.7	7.2	4.2	.012	.006
18	12	17	0.03	1.0	11.0	5.8	.022	.016
25	7	48	0.00	0.7	5.0	4.0	.007	.006
39.7	33		0.04	0.0	11.	7.1	.090	.091
41.7								
44								

B43

LAKE GREESON
6 - 1

Date 9-12-83

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.001	.25	.01	.06	16.3	1.4	1.9	0.8
4	.001	.21	.02	.04	9.9	1.4	1.9	0.8
10	.002	.17	.03	.05		1.3	2.0	0.8
13								
15	.003	.19	.11	.04	16.4	1.4	2.4	0.9
18	.006	.14	.14	.08	13.2	1.4	2.6	1.0
25	.006	.08	.02	.33	10.2	1.3	2.0	0.8
39.7	.074	1.08	1.00	.06	16.5	1.5	3.5	1.2
41.7								
44								

LAKE GREESEON

G - 1

Date 9-12-83

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	1.0	.04	.03	.02	.02
4	0.9	.04	.02	.03	.02
10	1.0	.68	.88	.21	.29
13					
15	1.1	1.17	1.03	.45	.47
18	1.1	1.39	.49	.76	.77
25	1.1	.65	.25	.23	.28
39.7	1.1	14.95	5.65	3.90	3.53
41.7					
44					

B45

LAKE GREESON
G - 1

DATE 10-24-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	20.1	5.7	6.0	21
1	20.2	5.7	6.0	21
2	20.1	5.3	6.0	21
3	20.1	5.5	6.0	21
4	20.1	5.8	6.0	21
5	20.1	5.7	6.0	21
6	20.1	5.7	6.0	21
7	20.1	5.6	5.9	21
8	20.1	5.7	5.9	21
9	20.1	5.7	5.9	21
10	20.1	5.7	5.9	21
11	20.1	5.6	5.9	21
12	20.0	5.7	5.9	21
13	20.0	5.7	5.9	21
14	20.0	5.7	5.9	21
15	19.2	0.5	5.8	34
16	17.2	0.3	5.7	34
17	16.0	0.3	5.8	33
18	15.0	0.3	5.8	30
19	13.2	0.2	5.7	24
20	12.0	0.2	5.7	22
21	11.0	0.2	5.6	22
22	9.9	0.7	5.6	21
23	9.0	2.2	5.5	17
24	8.6	2.5	5.5	17
25	8.3	2.7	5.5	17
26	7.8	3.7	5.4	15
27	7.7	3.6	5.5	15
28	7.5	3.4	5.4	15
29	7.5	3.2	5.4	15
30	7.3	2.7	5.4	15

10-24-83

Depth	Temperature (°C)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.1	2.4	5.4	15
32	7.0	0.7	5.4	18
33	6.9	0.3	5.3	27
34	7.0	0.2	5.5	33
35	7.0	0.2	5.6	55
36	7.0	0.2	5.7	61
37	7.0	0.1	5.7	82
38	6.9	0.1	5.9	91
39	7.0	0.1	6.0	112
40	7.1	0.1	6.1	128
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				

LAKE GREESON

G - 1

Date 10-24-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	10	5.3	0.00	1.3	2.6	2.4	.007	.006
4	9	5.1	0.00	1.2	4.3	2.3	.007	.006
10	9	4.6	0.00	1.6	2.6	2.4	.009	.007
13								
15	11	4.9	0.00	0.9	3.4	2.4	.010	.008
20	8	11.3	0.00	0.7	8.1	5.1	.013	.010
25	7		0.00		4.7	4.4	.007	.006
39.3	53	33.7	0.02	0.0	26.	6.7	.072	
41.7								
44								

B48

LAKE GREESON

6 - 1

Date 10-24-83

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.005	.2	.06	.10	8.5	1.5	2.2	0.9
4	.003	.4	.01	.06	9.8	1.5	2.3	0.9
10	.002	.3	.02	.07	10.3	1.5	2.2	0.9
13								
15	.003	.5	.11	.05	7.9	1.5	2.3	0.9
20	.011	.3	.10	.17	7.2	1.5	2.5	1.0
25	.011	.3	.03	.39	8.9	1.4	2.2	0.9
39.3	.078	1.3	.94	.14	14.9	1.5	3.6	1.3
41.7								
44								

LAKE GREESON

G - 1

Date 10-24-83

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	1.0	.21	.04	.21	.13
4	1.0	.21	.05	.17	.09
10	1.0	.24	.12	.16	.09
13					
15	0.9	.39	.21	.26	.21
20	1.0	1.43	0.40	.71	.70
25	1.0	.62	.48	.32	.36
39.3	1.2	17.20	14.30	3.93	3.72
41.7					
44					

B50

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

DATE 10-27-83

Station Designation	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
A	19.0	6.9	5.7	38
B	18.7	7.3	5.9	38
C	19.2	7.4	6.0	38
D	19.5	7.7	6.1	36
E	20.9	8.1	6.3	35
F				
G				
H				

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

DATE 10-27-83

Station Designation	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
A	19.0	6.9	5.7	34
B	18.7	7.3	5.9	34
C	19.2	7.4	6.0	34
D	19.5	7.7	6.1	32
E	20.9	8.1	6.3	32
F				
G				
H				

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 10-27-83

Station Designation	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
A	14	22.3	0.0	0.6	5.2	3.8	.019	.008
B	15	20.5	0.0	0.6	4.0	2.9	.010	.017
C	13	16.1	0.0	0.7	4.6	2.9	.026	.017
D	14	15.1	0.0	0.6	4.5	2.9	.015	.010
E	10	6.1	0.0	0.8	4.7	2.9	.012	.009
F								
G								
H								

Date 10-27-83

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Station Designation	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
A	.003	0.4	0.14	0.10	8.5	1.5	0.5	1.0
B	.004	0.6	0.13	0.04	7.9	1.5	0.6	1.0
C	.001	0.5	0.10	0.04	7.8	1.4	0.5	0.9
D	.001	0.6	0.07	0.05	6.8	1.4	0.5	0.9
E	.002	0.5	0.08	0.06	7.9	1.4	0.5	0.9
F								
G								
H								

LITTLE MISSOURI RIVER
BELOW NARROWS DAM

Date 10-27-83

Station Designation	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
A	1.0	.65	.31	0.39	0.35
B	1.0	.57	.26	0.37	0.30
C	1.0	.57	.23	0.35	0.27
D	1.0	.50	.15	0.26	0.00
E	1.0	.55	.24	0.26	0.23
F					
G					
H					

LAKE GREESON
G - 1

DATE 11-2-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	19.1	6.4	5.8	22
1	19.1	5.8	5.8	22
2	19.1	5.7	5.9	22
3	19.1	5.7	5.8	22
4	19.1	5.6	5.8	22
5	19.1	5.7	5.8	22
6	19.0	5.7	5.8	22
7	19.0	5.7	5.8	22
8	19.0	5.7	5.9	22
9	18.9	5.3	5.9	23
10	18.8	5.0	5.9	23
11	18.8	4.3	5.8	23
12	18.7	4.2	5.8	24
13	18.6	0.4	5.7	24
14	18.2	0.4	5.7	38
15	17.7	0.3	5.7	41
16	16.7	0.3	5.8	39
17	15.2	0.3	5.7	36
18	14.2	0.3	5.7	35
19	12.8	0.3	5.6	31
20	11.4	0.3	5.4	25
21	10.6	0.3	5.4	25
22	8.7	2.2	5.4	19
23	8.5	2.3	5.4	19
24	8.0	3.1	5.4	17
25	7.8	3.4	5.4	18
26	7.6	3.2	5.4	18
27	7.5	3.0	5.4	18
28	7.4	2.6	5.4	18
29	7.2	2.4	5.4	18
30	7.1	2.2	5.4	18

11-2-83

Depth	Temperature (°C)	Dissolved Oxygen mg/l.	pH	Specific Conductance umhos/cm
31	7.1	0.3	5.4	21
32	7.0	0.3	5.4	24
33	7.0	0.2	5.4	34
34	7.0	0.2	5.5	46
35	7.0	0.2	5.5	64
36	7.0	0.2	5.6	70
37	7.0	0.2	5.6	91
38	7.0	0.2	5.7	97
39	7.1	0.2	5.8	121
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				

LAKE GREESON
G - 1

DATE 11-8-93

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	18.2	5.4	5.8	22
1	18.4	5.2	5.8	23
2	18.4	4.9	5.8	23
3	18.4	4.9	5.8	23
4	18.4	4.8	5.8	23
5	18.4	4.7	5.8	23
6	18.4	4.7	5.8	23
7	18.4	4.7	5.8	23
8	18.4	4.6	5.8	23
9	18.4	4.7	5.8	23
10	18.4	4.7	5.8	23
11	18.3	4.7	5.8	23
12	18.3	3.1	5.8	24
13	18.1	0.6	5.8	29
14	17.9	0.4	5.8	32
15	17.6	0.5	5.7	42
16	17.2	0.4	5.7	43
17	16.2	0.4	5.8	38
18	15.0	0.3	5.7	34
19	13.4	0.3	5.8	32
20	11.8	0.3	5.8	25
21	10.6	0.3	5.8	23
22	9.8	1.2	5.7	22
23	8.9	2.0	5.7	18
24	8.6	2.3	5.6	19
25	8.2	2.6	5.6	17
26	8.0	2.9	5.5	17
27	7.8	2.9	5.5	18
28	7.7	2.5	5.5	18
29	7.5	2.2	5.4	18
30	7.4	2.0	5.4	18

11-C-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
31	7.2	0.4	5.4	19
32	7.2	0.3	5.4	22
33	7.1	0.2	5.4	42
34	7.1	0.2	5.4	48
35	7.1	0.2	5.6	63
36	7.2	0.2	5.6	71
37	7.2	0.2	5.7	86
38	7.2	0.2	5.7	93
39	7.3	0.2	5.8	114
40	7.3	0.2	5.8	136
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				

LAKE GREESON
G - 1

Date 11-8-83

Depth	Alkalinity (mg/L)	Free CO ₂ (mg/L)	Sulfide (mg/L)	Sulfate (mg/L)	Turbidity (NTU)	Diss. Silica (mg/L)	Total Phosphorus (mg/L)	Total Diss. Phosphorus (mg/L)
0	6	6.1	0.00	0.6	2.2	3.0	0.11	.006
4	8	6.2	0.00	0.6	2.2	2.5	0.15	.014
10	9	7.0	0.00	0.8	2.4	3.1	0.10	.006
13								
15	19	13.8	0.00	0.4	4.0	4.9	0.17	.006
18	16	17.4	0.17	0.7	3.3	5.9	0.11	.010
25	6	12.3	0.02	0.9	4.4	5.0	0.10	.013
39.3	58	45.4	0.04	0.5	5.8	8.4	0.78	.071
41.7								
44								

B60

LAKE GREESON

G - 1

Date 11-8-83

Depth	Soluble Reactive Phos (mg/L)	TKN (mg/L)	Ammonia Nitrogen (mg/L)	Nitrate Nitrogen (mg/L)	T.O.C. (mg/L)	Sodium (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
0	.009	.8	.09	.06	7.2	1.4	2.3	0.9
4	.003	.7	.03	.06	5.9	1.4	2.3	0.9
10	.007	.7	.09	.07	6.2	1.4	2.4	1.0
13								
15	.002	1.2	.33	.02	8.2	1.4	3.1	1.0
18	.006	0.9	.22	.03	7.6	1.4	2.5	1.0
25	.005	0.6	.04	.30	6.0	1.3	2.2	0.9
39.3	.067	2.3	1.4	.05	14.9	1.3	4.0	1.4
41.7								
44								

B61

Date 11-8-83

LAKE GREESON
6 - 1

Depth	Potassium (mg/L)	Iron		Manganese	
		Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
0	1.0	.15	.05	.15	.19
4	1.0	.14	.02	.18	.12
10	1.0	.13	.06	.19	.10
13					
15	1.1	1.08	.87	2.70	2.53
18	1.0	2.41	2.26	1.15	1.16
25	1.0	.44	.57	.26	.44
39.3	1.3	21.15	17.25	4.79	4.04
41.7					
44					

LAKE GREESON
G - 1

DATE 11-16-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
0	16.6	6.0	6.4	21
1	16.3	5.8	6.2	20
2	16.2	5.7	6.2	20
3	16.1	5.7	6.2	20
4	16.1	5.7	6.1	20
5	16.1	5.7	6.1	20
6	16.1	5.6	6.1	20
7	16.1	5.7	6.0	20
8	16.1	5.7	6.0	20
9	16.1	5.7	5.9	20
10	16.1	5.7	6.0	20
11	16.1	5.7	5.9	20
12	16.1	5.7	5.9	20
13	16.1	5.7	5.9	20
14	16.1	5.6	5.9	19
15	16.1	5.7	5.9	19
16	16.1	5.6	5.9	19
17	16.0	5.4	5.8	20
18	14.0	1.6	5.8	30
19	13.1	0.4	5.7	30
20	12.0	0.4	5.7	24
21	11.1	0.4	5.7	22
22	10.0	0.8	5.6	22
23	9.6	1.7	5.6	18
24	8.8	2.3	5.5	17
25	8.6	2.8	5.5	16
26	8.2	3.2	5.5	15
27	8.0	3.1	5.4	16
28	7.8	2.8	5.4	15
29	7.7	2.5	5.4	15
30	7.5	2.0	5.4	16

11-10-83

Depth	Temperature (°C)	Dissolved Oxygen mg/L	pH	Specific Conductance umhos/cm
31	7.5	0.7	5.4	16
32	7.4	0.4	5.4	24
33	7.3	0.3	5.4	30
34	7.3	0.3	5.4	47
35	7.3	0.3	5.4	59
36	7.4	0.3	5.5	69
37	7.4	0.3	5.5	75
38				
39				
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				